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Economic Analysis of the Controlled Drainage System: A Case Study of a Vegetable Farm in Ontario, Canada

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Abstract

Water availability for crop production in many parts of the world, including Eastern Canada, is important, including availability to the root zone of the crops. Water table management is suggested to overcome these issues, if adopted by producers. But such adoption decisions often depend on the financial returns to producers. In this study, financial returns of a controlled drainage system were estimated over a subsurface drainage system using a private accounting stance. The BMP provided an additional return to producer of CAD $10,287 per ha over the life of the project, associated with a benefit-cost ratio of 1.6, making it financially desirable on economic grounds.

Keywords: vegetable production, eastern Canada, controlled drainage system, financial analysis, net present value

1. Introduction

1.1 Farmers' Adoption Decision Making

Water resources world over are coming under increased pressure. Two factors that have exacerbated this situation include increased competition from other water users, and future changes in climate affecting water availability. Situation in eastern Canada, including the province of Quebec, is going to be no different particularly under climate change. In this province, irrigation and drainage practices are necessary to produce high value horticultural crops, such as fruits and vegetables. With an increasing population, decrease in water resources brought forward by climate change and competing uses from other sectors, the concern is that water for irrigation purposes might be less readily available in the future. This situation can pose serious economic risks to agricultural producers and environmental risks to habitats and ecosystems. To sustain both livelihoods and ecosystems, changes in the current agricultural practices, particularly in on-farm water management, are needed.

In eastern Canada, and in whole of Canada, need for improving water use efficiency cannot be overemphasized. The Government of Canada, through Agriculture and Agri-Food Canada (AAFC) has developed the Agriculture Greenhouse Gas Program (AGGP), with four priority areas of research: livestock systems, cropping systems, agricultural water use efficiency and agro-forestry (AAFC, 2017).

The producers are key players in deciding the success of technological progress, since their interests often differ from those of the governments, and their choices may also be different. However, farmers' decision to adopt new agricultural (including water management) technologies represents a complex series of options weighing several factors regarding economic and social nature (Kulshreshtha & Brown, 1993). Studies have suggested that a producer will invest in a new technology as long as the economic returns are greater than the returns received in the pre-investment situation (Shekhawat, 2007; Reimer et al., 2012; OECD, 2012). Prokopy et al. (2008) have suggested that farmers' income levels are hypothesized to have a positive relationship with their willingness to adopt new technologies or innovations. This is because, since most new technologies require relatively high initial investments, farmers with high incomes are more likely to make such investment and ultimately adopt such technologies. Moreover, producers with high incomes are more likely to benefit from tax incentives than low-income producers, and therefore they are more likely to adopt new technologies.

1.2 Water Management Practices

The water management practices are developed for improving water use efficiency, which include application of water to crops and the elimination of water from the crop field, a part of the water table management (WTM) system. Improved practices, also called best (or beneficial) management practices (BMP), try to be improve situations such as that the plant is provided water at all times with the amount necessary for its growth, but that it is sufficient so that there is no loss of water due to evaporation or runoff. Also, these practices have the capability to control the levels of the water table according to the stage of the growing season, control the efficient application of fertilizer, among others (OMAFRA, 2003). These BMPs lead to significant increases in crop yields, improve the quality of the marketable product and the soil, as well as prevent soil erosion (Allerhand et al., 2013; Nistor and Lowenberg-DeBoer, 2007).

Vegetable producers have a choice of two technologies: they can continue using the sub-surface drainage or adopt a new BMP of sub-surface drainage with sub-irrigation. In order for these producers to adopt the new technology, more information is needed on the economic change it would bring. Information on whether the BMP would improve their profitability for vegetable production is not available at present. This study was undertaken to fill this void.

1.3 Objectives of the Study

The objective of this study was to estimate the economic desirability of adopting the selected BMP Technology on a farm in Ontario, by calculating the benefits and direct costs associated with the new practice that may affect the producer's decision to adopt it. In addition, to examine the robustness of the economic results of desirability of the selected BMP through the simulation of changes in factors that could affect the performance of the new technology.

This economic desirability analysis was carried out in the framework of a benefit – cost analysis (private accounting perspective), also called financial analysis, as it was based on the incremental net benefits of the BMP Technology using the "with and without" criterion. In that sense, the benefits and costs associated with BMP Technology were compared with those generated when the new practice has not been adopted, a situation called Base Technology.

2. Method

2.1 Study Site Description

The study site selected for this study was called Holland Marsh, one of the most important region for vegetable production, not only in Ontario but also in Canada (Planscape, 2009; OMAFRA, 2019). The soils in this region are muck soil type, classified as a terric humisol, which have a humic texture, with an organic matter content of about 70-80%, and drain poorly (De Sena, 2017, Planscape, 2009). In the region, some 7,000 acres are devoted to more than 60 vegetables, including 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 region (Planscape, 2009; Tesfaendrias et al., 2010).

Ontario has a considerable horticultural production. In 2018, it accounted for approximately 44% of total vegetable production in Canada, which was 2.4 billion tonnes with a farm gate value of CAD $1.2 billion (Statistics Canada, 2019a; 2019b). In the same year, the most produced vegetable in the country was carrot, generating a farm gate value of CAD $129.9 million and Ontario contributing with CAD $43.5 million. Dry onion was the next most-produced vegetable nationwide, after tomato, generating a farm gate value of CAD $94.6 million, with Ontario accounting for CAD $34.8 million (Statistics Canada, 2019a).

In 2019, the harvested area of carrots in Ontario was 48,660 ha, which accounted for about 48.2% of the total carrot harvested area in Canada (Agriculture and Agri-Food Canada, 2020). Carrot production is mostly concentrated in southern Ontario, where Chatam-Kent County produces around 50% of the total every year. The other half of the production comes from the Holland Marsh area, which includes 40% of York region and 60% of Simcoe County, in central-west Ontario (OMAFRA, 2018a). In the same year, Ontario reported a production of 101,885 tonnes of dry onions (marketable) in 2,291 ha, which represented about 42% of the total dry onion harvested area in Canada (Statistics Canada, 2019a). Between 65 and 75% of the total onion production in Ontario come from the Holland Marsh (Tesfaendrias et al., 2010).

The 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. Onions need watering during the time of formation and filling of the bulb, while carrots during the spring to help germination of the seed (Tesfaendrias et al., 2010). In fact, the optimum soil water content is 54.6% for carrot production (White, 1992). 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).

The two research fields were located in the Holland Marsh region, consisting of two commercial farms of 4.05 ha (or about 10 acres) and 6.07 ha (or about 15 acres) each. Both farms had a 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. The soil water enters by infiltration to the laterals and these transfer the water to the main tile (B. Singh, personal communication, October 24, 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).

2.2 Study Scenarios

One of these farms (Farm I) maintained the subsurface drainage (as noted above the Base Technology). The main tile drain was 397.5 m long and the lateral tile lines were spaced at 16 m apart. The length of the lateral drainage perforated pipe was estimated at 601.75 m/ha by interpolating the value from the guide on drainage system´s installation provided by Simundsson et al. (2016). In addition to the conventional drainage system, the other commercial farm (Farm II) had 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) main tile and the other led to the well. The structure had two guides, opposite each other on the walls of the structure, in which several stackable gates (stoplogs) can be accommodated within the structure. The gates acted as a blockage to prevent water from free-flowing out of the farm and their established height regulated the water table within the field (De Sena, 2017; B. Singh, personal communication, October 24, 2018). Therefore, the installation of the water level control structure converted the base system into a controlled drainage system (denominated as the BMP Technology).

Farm II is smaller than Farm I. Its main tile drain was 265 m long and had nineteen lateral tile lines which were spaced at 9 m apart (B. Singh, personal communication, October 24, 2018). The estimated length of the lateral pipe needed was 1090 m/ha, using Simundsson et al. (2016), requiring almost 495 m more pipe per ha on the Farm II.

Regarding crop production, both study farms grew various types of vegetables, but the crop rotation pattern of each farm in recent years was carrot-onion in different cycles (G. Grenon, personal communication, February 25, 2019). This analysis assumed that carrots and onions are produced in a three-year cycle rotation (two consecutive years of carrot followed by one of onion) in Farm I (under the Base Technology), while in Farm II (BMP Technology) it is a four-year cycle (three consecutive years of carrots and followed by one year of onions).

2.3 Sources of Data and Analysis of the Beneficial Management Practice

Data needed for the financial analysis were obtained from several sources. Details for other components in the design of the two systems were obtained from Essien (2016). In fact, the costs of installing both the Base and BMP technologies are very similar, except for the water level control structure and its installation. The price quoted by Agri Drain Corporation (2019 price list) for the control structure, suitable for an area of 4 ha, was US$1,094.34, included as 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 all piping were obtained from the 2019 retail price list through a quote to Soleno Inc. -- a drainage tile contractor listed in the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA). The total price of the accessories (the joints, tees, tapes, etc.) was calculated as 3% of the piping cost, suggested by the technical guideline publication by the Quebec Reference Center for Agriculture (CRAAQ, 2010), as well as the cost of the land preparation, which was updated to 2018 prices using the Machinery and Equipment for Crop and Animal Production Price Index (Statistics Canada, 2019c). This price index was also 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 hectares of farmland and the pump could serve approximately 4 hectares. Investment costs associated with both the technologies totaled CAD $6,137 and CAD $6,628 per ha for the Base Technology and BMP Technology, respectively (Table 1). Thus, to install a controlled tile drainage system on an existing subsurface tile drainage system cost CAD $490.47 per ha more.

Table 1. Cost of investment for Base Technology and BMP Technology (CAD $/acre)

Item	Total Cost of Base Technology (CAD $/ha)	Total Cost of BMP Technology (CAD $/ha)
Cost of the components:	**4,742.76**	**5,093.12**
Piping:		
100 mm diameter lateral tile	1,989.45	1,989.45
150 mm diameter main tile	922.30	922.30
200 mm diameter non-perforated pipe	29.75	29.75
Split couplings, tees, tapes, etc.	88.24	88.24
Outlet (250 mm)	172.23	172.23
Water table control:		
Control structure	0.00	350.36
Well	339.52	339.52
Pump	1,201.08	1,201.08
Cost of installation:	**1,271.30**	**1,271.30**
100 mm diameter lateral tile	1,031.20	1,031.20
150 mm diameter main tile	235.19	235.19
200 mm diameter non-perforated pipe	4.92	4.92
Control structure (Inc. Transport)	0.00	56.69
Cost of land preparation:	**123.20**	**140.08**
Total Investment Cost	**6,137.25**	**6,627.72**

Source: Detail 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, 2019c).

For the estimation of revenues, data on carrot yield for the growing season 2015 and 2016 for both technologies and both study farms were obtained from De Sena (2017). Carrot prices for those years were obtained from the annual average price of the horticultural crops report in Ontario (OMAFRA, 2018a). The average provincial onion yields and prices were used in this study, obtained from the horticulture report by OMAFRA (2018b). 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. These yields are shown in Table 2.

Table 2. Carrot revenues with Base Technology and BMP Technology

Year	Price ($/kg)	Base Technology		BMP Technology	
		Yield (kg/ha)	Gross Revenue (CAD $/ha)	Yield (kg/ha)	Gross Revenue (CAD $/ha)
2015	0.2316	85,131	19,716.32	70,582	16,346.41
2016	0.2281	59,165	13,495.68	61,417	14,009.53

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

Among the fixed costs considered were the cost for maintenance and repair of both systems´ components, and the depreciation of existing machinery and equipment on the farm. The maintenance and repair costs of the pipe system and the pump were estimated as a fixed percentage, 0.25% and 1% respectively, of their initial investment cost (Evans et al., 1996). No cost was assumed for the well as suggested by Evans et al. (1996). Agri Drain Corporation (2019) recommends the lubrication of the stoplogs as the only maintenance of the control structure. Following (Crabbé et al., 2012), this cost was estimated assuming 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), which meant two hours of work at CAD $18.50 per hour, calculated as the average agricultural work wage in Ontario obtained from ESDC (2019), plus the lube that costs US$9.41 (CAD $12.20) per tube for each application. Depreciation of existing capital assets were estimated in accordance with the operating budget developed by the Quebec Reference Center for Agriculture, for a farm producing carrots and onions, with good technical and economic efficiency (CRAAQ, 2008). These included a shed, a warehouse with refrigeration, and machinery and equipment of the farm, with depreciation rates of 3% (of $656.67/acre), 3.6% (of $1,440.28/acre), and 7% (CAD $5,199.29/acre), respectively. They were updated to 2018 prices using the Farm Input Price Index (Statistics Canada, 2019d) for depreciation on machinery and equipment in Ontario. Therefore, the total annual fixed cost of the Base Technology was estimated at CAD $1,585 per ha while that for the BMP Technology at CAD $1,600 per ha, the difference between the two systems was the cost of the control structure maintenance (Table 3).

Table 3. Fixed costs under Base Technology and BMP Technology ($/ha)

Item	Base Technology (CAD $)	BMP Technology (CAD $)
Repair and maintenance:		
Piping	8.01	8.01
Well	0.00	0.00
Pump	12.01	12.01
Control structure	0.00	15.17
Depreciation on existing capital:		
Shed of machinery and equipment (3%)	70.70	70.70
Warehouse with refrigerated section for carrot (3.6%)	186.39	186.39
Machinery and equipment (7%)	1,308.25	1,308.25
Total Fixed Costs	**1,585.32**	**1,600.49**

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 were estimated using data obtained from different sources due to a lack of budgets for production costs of horticultural products for Ontario. For the two technologies, costs were very similar, except for fertilizer cost, which was lower under the controlled drainage system because the control structure was effective to retain the nutrients in the field and avoid additional application of fertilizer throughout the growing season (De Sena, 2017). Carrot and onion seeds included were 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 (2019 price list) from Stokes Seeds Inc. (2019). Details on fertilizers and micronutrients used for carrots were obtained from the on-site study (De Sena, 2017), while suggestions of McDonald et al. (2018) and Zandstra et al. (1986b) for muck soils were followed for onions. 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). The quantity used of pesticides for carrot and onion production and their market prices were obtained from the guideline provided by the Quebec Reference Center for Agriculture (CRAAQ, 2008), given that the majority of carrot and onion production occurs in Ontario and Quebec, so they also share the issues regarding pests (AAFC, 2018a). All costs were updated to 2018 prices using the farm input index price for pesticides (Statistics Canada, 2019d). The hours of labor required for farming operations were taken from the publication for vegetable farms in Quebec (CRAAQ, 2008). Then, costs charged per hour for other operation activities (chiseling, sowing, application of fertilizer and spraying of agrochemicals, weed control, miscellaneous as snow removal, etc.), were obtained from the Ontario´s custom farm work rates survey (OMAFRA, 2018c). Although these costs were for general activities, they were considered a good approximation for the production of horticultural crops. The largest cost items in both carrot and onion production was that for seed (Table 4). Cost on per ha basis were slightly lower for the BMP technology compared to the Base technology for both carrots and onions.

2.4 Financial Analysis

The evaluation of the financial desirability of the controlled drainage system (BMP Technology) was conducted by developing a simulation model. The benefits and costs associated with both technologies were estimated using a budgeting technique, since the incremental net benefits of the BMP Technology were calculated subtracting the net benefits under the Base Technology from the net benefits under the BMP Technology. The salvage value of the systems´ components (piping, pump, well and control structure), calculated at the end of the useful life, was included as a negative cost in the last year of the cost stream (assuming that the asset was installed in the year that the project began). The performance of the investment was evaluated over the useful life of the BMP Technology, assumed in 20 years based on the useful life estimated for the control structure (Agri Drain Corporation, 2019; Kitchen and Kitchen, 2017; Crabbé et al., 2012; Evans et al., 1996).

Table 4. Operating costs under Base Technology and BMP Technology

Item	Carrot		Onion	
	Base Technology (CAD $/ha)	BMP Technology (CAD $/ha)	Base Technology (CAD $/ha)	BMP Technology (CAD $/ha)
Inputs				
Seed	1,911.02	1,911.02	1,945.52	1,945.52
Fertilizer	705.69	407.25	407.25	235.02
Insecticides	124.54	124.54	128.42	128.42
Herbicides	247.20	247.20	254.86	254.86
Fungicides	145.67	145.67	150.16	150.16
Cover crop	24.41	24.41	0.44	0.44
Sub-total Inputs	**3,158.53**	**2,860.09**	**2,886.65**	**2,714.42**
Farming Operations				
Chisel plow	22.09	22.09	22.09	22.09
Rotary disc	34.12	34.12	20.04	20.04
Seeding of cover crops	5.21	5.21	5.21	5.21
Fertilizer application	3.24	3.24	6.47	6.47
Seeding	77.02	77.02	77.02	77.02
Agrochemical spraying	36.92	36.92	61.53	61.53
Irrigation	6.99	6.99	10.50	10.50
Weed control	150.06	150.06	7.09	7.09
Harvesting	368.92	368.92	368.92	368.92
Miscellaneous	301.46	301.46	301.46	301.46
Hired labor	411.42	411.42	411.42	411.42
Sub-total Farming Expenses	**1,417.44**	**1,417.44**	**1,291.74**	**1,291.74**
Total Operating Costs	**4,575.97**	**4,277.53**	**4,178.39**	**4,006.16**

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).

Three indicators were used to evaluate financial desirability in this study: net present value (NPV), benefit-cost ratio (BCR), and pay-back period (PBP). Details on their calculation are shown in Table 5. Under the net present value analysis, the time value of future benefits and costs are taken into account. In other words, they were expressed in present-day values by discounting, and compared to the investment initial cost of each technology. The inflation rate was not included in the analysis since it affects equally to both inputs and output prices (Singh and Christen, 2000).

The discount rate was estimated at 8.78% using the weighted average cost of capital suggested by Boehlje and Eidman (1984), which consists of assigning weights to the costs of debt and equity (Equation 1), which leads to return on investment after-tax.

$$r = K_e W_e + K_d (1 - t) W_d \quad (1)$$

Where, r is the discount rate, Ke is the rate of return on equity capital, We is the proportion of equity capital, Kd is the interest rate on debt, t is the income tax rate, and Wd is the proportion of debt. The return on equity used was 10.2% based on estimations developed by Farm Credit Canada of the Canadian farming sector return on equity (ROE) for the 2018-2019 fiscal year (FCC, 2018). The interest rate used was 3.64% 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, as the 10-year average (2008-2017) of the equity/asset and debt/asset ratios calculated for Ontario (Statistics Canada, 2019b). The income tax rate used was 20%, as a reasonable rate of taxable income in the province (CRA, 2018).

Table 5. Desirability indicators used for financial evaluation.

Desirability indicator	Formula	Decision criteria	Unit
Net present value (NPV)	$\sum_{t=0}^{n} \frac{B_t}{(1+i)^t} - \sum_{t=0}^{n} \frac{C_t}{(1+i)^t}$	NPV > 0	\$/acre
Benefit-cost ratio (BCR)	$\sum_{t=0}^{n} \frac{B_t}{(1+i)^t} / \sum_{t=0}^{n} \frac{C_t}{(1+i)^t}$	BCR > 1	\$ gained for every \$1 spend
Pay-back period		$PBP = p$	p is no of years

The revenue and production cost data for the 20 years of the project´s life span (2019-2038), were projected based on a stochastic simulation using the random number generation tool of the R-Project program. A skew-normal distribution to forecast prices and crop yields was assumed, based on the reviewed literature that found marked skewness and kurtosis in statistical distribution of commodity prices and crop yields (Trautman et al., 2012; Ramírez et al., 2003; Atwood et al., 2003). The coefficients: mean, standard deviation, and skewness (positive or negative) of these variables were calculated for the historical data available. Market prices for the period 1979-2018 were obtained from OMAFRA (2018a; 2019b). Since carrots yields were limited to 2 years in this site (2015 and 2016), the average yield data reported by the province were used to estimate the standard deviation and skewness coefficients. For onions yield data instead, the three coefficients were calculated from the average annual yield data reported by the province (OMAFRA 2018a; 2019b). On the other hand, the operating costs were forecasted using a normal distribution, based on results of risk analysis (for agricultural insurances) studies (Jacques, 2014; Sossou et al., 2014). Foremost, 10 years of data (from 2018 to 2027) were estimated using the Farm Input Price Index Projections provided by AAFC (2018b), from which were obtained the mean and standard deviation for forecasting the rest of the years until 2038.

2.5 Sensitivity Analysis

The financial performance of the BMP Technology may be affected by variations in certain economic and non-economic factors due to uncertainties associated with future events. The evaluation of the robustness of desirability indicators involved four factors for both Base and BMP Technology: crop price, crop yield, investment cost, and discount rate, and the estimation of the break-even point in each one.

2.5.1 Change in Crop Prices

The medium-term outlook developed by AAFC has foreseen an increase of 1.8% for vegetable prices by 2027, which constitutes a slow recovery to the fall in the fruit and vegetable market in 2017 when prices decreased by 1.9% (AAFC, 2018b). On the other hand, there are some reasons why the production of vegetables is increasing during the last few years, among them is the creation of new and more reliable horticultural production practices, 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). These improved farming practices are positive for productivity; however, the increase in supply and large stocks could bring prices down in the future. Thus, 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 prices for the period ending 2038.

2.5.2 Change in Crop Yields

This study assumed that carrot and onion yield variations will be mainly because of changes in future climate patterns. According to statistics, in the period 1948-2016, the temperatures in Ontario have increased by up to 1.3°C annually on average (Cohen et al. 2019), and rainfall occurrences have become more variable since 1950, especially in the region southwest of the province (Chiotti and Lavender, 2008). By 2050, temperatures increase of up to 3.3°C are projected over the 1981-2010 base period. For rainfall, results ae mixed (Morand et al., 2017; Qian et al. 2019).

Studies have suggested that 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). McKeown et al. (2005) reported yield losses in many vegetables when they were exposed to temperatures above 30°C coupled with fewer days with rainfall. A review of the literature revealed that the growth, maturity and marketable yield of carrots and onions are highly influenced by weather conditions. Adequate water availability (especially for the development of the bulb) and fertile soils are critical factors for the growth of onions (Rekila et al. 2014). Hussain et al. (2008) found that the optimum good-quality carrots grow with a temperature not greater than 21°C, while De Ruiter (1986) concluded that for the best onions production, no higher than 26°C is ideal. Based on the above information, it is expected vegetable yields would decrease in a future climate change scenario. Sorensen et al. (1997) reported a reduction of up to 28% in marketable carrot yields during drought periods in research conducted in sandy loam soils. That percent variation was used in this sensitivity analysis for carrot and onion yield variation, along with simulated reductions of 7%, 14%, while for an optimistic scenario, a 7% yield increase was considered.

2.5.3 Change in Discount Rate

Since the choice of the discount rate takes into account the potential relative risk of the investment (Selvavinayagam, 1991), previous studies used different discount rates when undertaking 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% (Essien 2016; Tyndall and Roesch-McNally 2014), 5% (Bogdan 2019) and 10% (Trautman et al., 2012).

3. Results

3.1 Financial Evaluation

The financial viability of both subsurface drainage system (Base Technology) and controlled drainage system (BMP Technology) was undertaken over 20 years of project life (2019-2038) and using a discount rate of 8.78%. Both technologies were found to be financially desirable since their NPV indicators are positive (Table 6). However, the BMP technology was the most attractive alternative, with an incremental net benefit of CAD $10,287 (about 34.7%) per ha over the net returns under the Base Technology, over the project´s life. This means that the controlled drainage system provides 34.7% higher profits relative to the conventional subsurface drainage system. The BCR indicators are greater than 1, following the decision rule, which means that the producer earns for his investment about 60 cents for every CAD $1 spent per acre. Furthermore, the time required to earn back the investment is less than a year. Therefore, the results on financial analysis suggest that producing carrots and onions in a rotation system using the controlled drainage technology is economically more attractive than a system without the control drainage.

Table 6. Financial indicators of the desirability of Base Technology and BMP Technology

Indicator	Base Technology (Subsurface Drainage)	BMP (Controlled Drainage)
Net Present Value r=8.78% (CAD $/ha)	29,612	39,899
Benefit-Cost Ratio (gain for every CAD $1 spent/ha)	1.5	1.6
Pay-back Period (year)	0.9	0.7

3.2 Results of Sensitivity Analysis

The conclusions on the financial desirability of the BMP Technology over the baseline scenario do not change if the carrot and onion prices increase by 1.8% (suggested by the forecasts) as shown in Table 7. Likewise, if prices were to decrease by 1.9 or 5%, the BMP Technology continues being the most financially desirable option. Under these scenarios, the other indicators (BCR and pay-back period) remain without significant changes. However, in the hypothetical scenario that carrots and onions prices decline by 50%, then both technologies are no longer viable. The results also revealed that crop prices have to decline in more than 31% for the NPV of the Base Technology to become zero, whereas that for the BMP Technology, the prices decrease would have to be in about 38.8% with respect to the baseline scenario.

Table 8 shows the change in financial indicators if the carrot and onion yields changes under likely future climatic adverse effects on crop yields. As expected, an increase in yields of both crops by 7% maintains the BMP Technology as the most desirable option compare to the Base Technology. However, yield reductions decrease the financial attractiveness of the technologies. In the scenario of a yield reduction of 14%, for example, the NPV indicators decrease by around 83% and 67% with the Base Technology and BMP Technology, respectively. However, in both 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 would become unattractive on financial grounds. The break-even yield level for this site indicates that the controlled drainage technology (BMP) would continue to be worthwhile even if there is a reduction in the yields of both carrot and onion by 17.2%, but the Base Technology would no longer be a viable alternative. On the other hand, when the percentage of decrease in yields is as low as 21.8%, the BMP would produce losses as well.

Table 7. Sensitivity of financial indicators of the Base Technology and BMP Technology to change in carrot and onion prices

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.	31,310	29,612	27,821	24,898	-17,539	**0**	-7,000
	BMP Tech.	41,750	39,899	37,947	34,762	-11,485	7,630	**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

* Percent change from the base simulation

** Results of base simulation

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

Table 8. Sensitivity of financial indicators of the Base Technology and BMP Technology to change in carrot and onion yields

Financial Indicator	System	% Change in Crop Yield*						
		+7%	0%**	-7%	-14%	-28%	Break-Even Yield -17.175%	-21.784%
NPV[1]	Base Tech.	43,277	29,613	16,872	5,056	-15,805	**0**	-6,998
	BMP Tech.	54,792	39,899	25,348	13,138	-9,595	7,630	**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

* Percent change from the base simulation

** Results of base simulation

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

The discount rate sensitivity analysis (see table 9) shows that the NPV indicators of technologies increase as the discount decreases. With the lower discount rate of 3.75%, the NPV values in both cases are higher, increasing up to 60% with the Base Technology, and up to 56% with the BMP Technology. With the controlled drainage system (BMP) being the most attractive alternative at all times. Furthermore, increasing the discount rate from 8.78% to 10% results in a decrease of NPV values by 9.9% and 9%, respectively, for the Base and BMP technologies. However, the BCR and pay-back period indicators remain the same under any scenario. Therefore, regardless of the discount rate scenario analyzed, the controlled drainage system (BMP) maintains its better financial attractiveness compared with the conventional subsurface drainage system. The break-even discount rates, referred to as the internal rate of return (IRR), indicate that the discount rate would have to be greater than 76.9% for the Base technology to cease to be financially viable. On the other hand, a discount rate of more than 125% would be necessary for the NPV indicator in the BMP Technology to be zero. This implies that the investment in both technologies would be highly 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 9. Sensitivity of financial indicators of the Base Technology and BMP Technology to change in discount rate value

Financial Indicator	**System**	**Level of Discount Rate**					
		10%	**8.78%***	**5%**	**3.75%**	**Break-Even (IRR)**	
						76.89%	**125.6%**
NPV[1]	Base Tech.	26,684	29,612	41,916	47,446	**0**	-1,838
	BMP Tech.	36,301	39,899	55,217	62,195	3,017	**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

* Rate used for the base simulation

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

4. Discussion

This study was undertaken using data available on the relevant characteristics of the study farm, such as cultural practices (most commonly rotation patterns, fertilizer application, labor, etc.), as well as the design and characteristics of the baseline system (subsurface drainage) and the experimental beneficial water management system (controlled drainage). The budgets used for the analysis where developed based on average costs estimated according to data available for a profitable farm with good performance in the region where the greatest production of vegetables is concentrated.

The farm-level economic evaluation concluded that the controlled drainage system is a more desirable alternative when compared to the conventional subsurface (tile) drainage system. Controlled drainage system improves yield of carrots and onions. The incremental costs of installation are only CAD $15 per ha, which constitute less than one percent of the total cost of installation. Furthermore, the BMP Technology performance is robust to changes in some economic and non-economic factors. The prices of crops in the market (for carrots and onions) could vary (decrease) without affecting immediately the financial attractiveness of the BMP Technology. Even climate change, that is expected to play an important role in the variability of horticultural crop yields, does not have very severe results on the desirability indicators that can quickly put at risk the attractiveness of the controlled drainage system.

This study has undertaken the farm-level economic analysis in two commercial vegetable producing farms in Ontario. The study involved a comparison of the controlled drainage system as the BMP Technology and the conventional subsurface drainage system as the Base Technology. Moreover, it was assumed that onions and carrots are grown in a three-year cycle rotation (two consecutive years of carrot followed by one of onion) under the Base Technology, and four-year cycle (three consecutive years of carrot and followed by one year of onion) under the BMP.

This would imply that producers from Ontario, who are involved in vegetable production and whose farms have the characteristics of this case study, may be interested in adopting the improved water management practice since it is an alternative that will allow them to generate higher net returns than those generated by the current drainage technology. The technology is even more attractive because the time to recover the investment is very short.

5. Data Availability

Some data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request. All data, models, and code generated or used during the study appear in the submitted article. Some data, models, or code used during the study were provided by a third party. Direct requests for these materials may be made to the provider as indicated in the Acknowledgements.

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