The economics of controlled drainage with sub-irrigation and field drainage in Quebec

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ABSTRACT

Based on evidence from scientific studies, increases in Greenhouse Gas (GHG) emissions are a contributing factor to climate change that have global implications. Climate change has the potential of having detrimental effects on environmental quality and sustainability. Canada, as a member of the United Nation Framework Convention on Climate Change (UNFCCC) is committed to reducing its GHG emissions. As a result of this commitment, the Agricultural Greenhouse Gas Program (AGGP) was established to undertake research in order to develop and implement GHG mitigation strategies. The AGGP partnered with the Brace Centre for Water Resource Management to investigate water table management (WTM) systems that could have the potential for increasing yields and reducing GHG emissions. The purpose of this research was to evaluate the on-farm and off-farm costs and benefits of alternate drainage technologies. Benefit-cost analysis (BCA) was used to determine the Net Present Value, Internal Rate of Return and Benefit Costs Ratio of Controlled drainage with Sub-irrigation (CDSI) and Tile/Field Drainage (FD). The on-farm private benefit-cost analysis was based on data from a project site in St. Emmanuelle, Quebec. The historical yield data were based on data gathered from the site between 1993 and 2014 and projected for the next 20 years (useful life of the irrigation system) prices and costs were projected from 2015 to 2034. There was no statistically significant difference in the yields between the two irrigation systems. The Benefit Cost ratio for installing CDSI was 1.03 and 1.13 for FD. The net present value (NPV) at a 3.75% discount rate was C$713.12 for CDSI and C$1,501.5 for FD. An estimation of off-farm benefits was performed, by incorporating GHG emissions costs into the analysis and the results revealed a Benefit Cost Ratio of 1.01 and 1.12 for CDSI and FD respectively. Based on these results, it would be preferable for farmers to adopt FD, which is the status quo, situation.

RÉSUMÉ

Sur la base des données provenant d'études scientifiques, l'augmentation des gaz à effet de serre (GES) provoque le changement climatique et ont des implications mondiales. Le changement climatique a le potentiel d'avoir des effets néfastes sur la qualité de l'environnement et de la durabilité. Canada, en tant que membre de la Convention-cadre des Nations Unies sur les changements climatiques (CCNUCC) est engagé à réduire ses émissions de GES. À la suite de cet engagement, le programme agricole de gaz à effet de serre (PLGESA) a été créé pour entreprendre des recherches en vue de développer et mettre en œuvre des stratégies d'atténuation des GES. Le PLGESA en partenariat avec le Centre Brace de gestion des ressources en eau pour enquêter sur la gestion de la nappe phréatique (WTM) des systèmes qui pourraient avoir le potentiel pour augmenter les rendements et de réduire les émissions de GES. Le but de cette recherche était d'évaluer la à la ferme et hors ferme des coûts et des avantages des technologies de drainage alternatives. L'analyse coûts-avantages (ACA) a été utilisé pour déterminer la valeur actualisée nette, taux de rendement interne et de prestations Coûts Ratio du drainage contrôlé et sous-irrigation (DCSI) et Tile/Champ Drainage (CD). L'analyse coûts-avantages privé à la ferme a été fondée sur des données provenant d'un site de projet à St. Emmanuelle, Québec. Les données de rendement historiques ont été basées sur des données recueillies à partir du site entre 1993 et 2014 et prévues pour les 20 prochaines années (durée de vie utile du système d'irrigation) prix et les coûts ont été projetés à partir de 2015 à 2034. Il n'y avait pas de différence statistiquement significative dans les rendements entre les deux systèmes d'irrigation. Le ratio du coût des prestations pour l'installation DCSI était de 1,03 et 1,13 pour CD. La valeur actuelle nette (VAN) à un taux

d'actualisation de 3,75% était 713,12 $ CA pour CDSI et 1,501.5 $ CA pour FD. Une estimation des avantages hors ferme a été réalisée, en intégrant les coûts des émissions de GES dans l'analyse et les résultats ont révélé un ratio coûts-avantages de 1,01 et 1,12 pour CDSI et FD respectivement. Sur la base de ces résultats, il serait préférable pour les agriculteurs à adopter FD, qui est le statu quo, la situation.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Global Climate Change is increasingly becoming a source of concern due to its global warming potential. Scientific assessments by the Intergovernmental Panel on Climate Change (IPCC), have presented reports which suggest that increases in greenhouse gases, amongst other factors, are at the heart of issues causing climate change and leading to global warming. Global greenhouse gas (GHG) emissions increased by about 1.3% annually from 1970 to 2000 and by 2.2% annually from 2000 to 2010. Increases in global average temperature have been greater in the last 20 years than the overall average since 1901 (IPCC, 2007).

Climate change refers to changes in the properties of the atmosphere caused primarily by human activities; some of these changes include an increase in average temperature and unbalanced precipitation (i.e., excess water or inadequate water supply) that may have detrimental effects on society through the occurrence of increased flooding or increased incidence of drought (IPCC, 2007). However, at the same time, climate change through an increase in atmospheric temperature may have some positive impacts on crops like corn and soybean production in cooler regions (Bootsma et al, 2005).

Generally, the demand for natural resources, e.g., freshwater resources, is fast exceeding the economic supply, and the competition among the various sectors of the economy for scarce water is becoming intense, which may cause severe risks to agricultural producers and environmental risks to habitats and ecosystems. Results may be in terms of food shortages, economic crises, and poverty (UNFCCC, 2002). Globally, approximately 70% of the freshwater is withdrawn for agricultural use (FAO, 2015). In Canada, the agricultural sector consumes over 80% of the water withdrawn (Statistics Canada, 2014).

In response to these demands, decision makers, researchers, and farmers are progressively pursuing innovative, technological, and institutional interventions to enable the efficient, equitable and sustainable utilization of scarce natural resources to ensure environmental sustainability. The agricultural sector is typically comprised of intensively managed systems and changing the management practices could potentially provide a way to reduce agricultural greenhouse gases (Gregorich et al, 2005). To achieve agricultural sustainability and improvements in environmental quality, beneficial management practices (BMP) have to be developed and implemented.

In a bid to tackle these issues and support the global response to improving environmental quality, Canada, a member of the United Nations Framework Convention on Climate Change (UNFCCC), agreed in Copenhagen 2009, to find methods of reducing its GHG emissions by 17% from the level in 2005 by 2020 (IPCC, 2007). As a result of this commitment, the Agricultural Greenhouse Gas Program (AGGP) of Agriculture and Agri-Food Canada (AAFC) in partnership with Global Research Alliance team supported research to find beneficial water management practices that reduce agricultural GHG emission and disseminate this information through the Brace Water Management Center (Madramootoo et al, 2010). Canada is dedicated to meeting its GHG reduction targets by committing to reduce about half the emissions to meet Canada's 2020 target whilst attaining increases in agricultural productions through innovative management practices. Canada has further agreed to reduce her GHG emissions under the Paris Agreement in 2015.

All sectors of the economy have to come together to address the multi-faceted and multi-disciplinary issue of climate change. The farming sector, for instance, plays a vital role because it has the potential of becoming a GHG sink. Agriculture contributes about 8% to overall GHG emissions in Canada. Within the farming sector, over 40% of the GHG emissions are from agricultural soils (Environment Canada, 2012), although a greater portion of GHG emissions from agriculture stems from enteric fermentation rather than crop production. To achieve the target of turning the farming sector from a producer to a sink for GHGs, agriculture will need to adopt more sustainable management practices.

Canada is the 11th largest corn producer in the world, (FAO, 2011) making it an economically important nation. Ontario and Quebec, respectively, produce approximately 66% and 33% of all corn grown in Canada (corn for grain, corn for silage and sweet corn) respectively. Consequently, corn production covers a large portion of the arable land in the region (Statistics Canada, 2011). Thus, the demand for fertilizer and water management practices (e.g. Water Table Management), which reduces pollution, increases water use efficiency, nitrogen use efficiency and productivity, are rapidly increasing.

In Quebec, the area devoted to corn increased from 1.1 Mha in 1996 to 1.37 Mha in 2011 (Statistics Canada, 2011). Although the humid lowlands of Quebec usually require drainage (as it is characterized by excess water) in summer, drought-like conditions often occur due to infrequent precipitation and high evapotranspiration. During the growing season, insufficient rainfall in this region can serve as an important climatic factor which could impede grain yields in fertilized corn, predominantly in July, when crop yields in subsurface-drained fields are reduced because of dry spells and excessive drainage (Drury et al, 1996).

Water Table Management (WTM) is the practice of controlling ground water through a combination of subsurface drainage, controlled drainage with/without sub-irrigation (Madramootoo et al, 1993). These systems have the potential to provide adequate aeration and soil moisture to crops all year round thereby minimizing the risk of crop losses due to unbalanced precipitation. The WTM improves drainage water quality by reducing nitrate losses from the soil profile; in so doing retaining Nitrate-N in the soil profile for crop use which increases corn production efficiency. WTM systems are usually installed beneath the soil surface and thus it does not create obstacles in the field like above ground irrigation systems. This makes it suitable for grain crops like soybean or corn. Also, they require less energy, water and labour, making them more economical than some surface irrigation systems (Doty et al, 1983; Madramootoo et al, 2000).

WTM has been embraced by scientists, farmers and environmentalists as a method of reducing agricultural pollution and improving yields at the farm level. Nonetheless, installation of this technology by farmers in eastern Canada is not widespread because of its high capital cost and therefore it has been used mainly on large farms or experimental sites. In recent times, sub-irrigation with controlled drainage technologies have undergone some technical transformations from generally sophisticated and capital-intensive features to less complex features and reduced costs to cater to smaller plots or smallholder farms (Polak et al, 1997; Shah and Keller, 2002; Verma et al, 2005). With an increase in commodity prices, scientists are hopeful that the potential increase in yield that could result from implementing this technology will compensate for the installation costs.

A review of the literature on the impacts of sub-irrigation with controlled drainage technologies indicate that they have potential economic benefits through increases in crop yields, better output quality, nitrogen use efficiency, water use efficiency and adequate water supply (Belcher and D'Itri, 1995; Elmi et al, 2000; Gaynor et al, 2000). However, the cost savings differ considerably depending on the location due to differences in crop, soil, topography, climate, water supply, and degree of management. Also, there is very little information on the relationship between these technologies and its GHG mitigation potential on the average farm field. Thus, the introduction of sub-irrigation with controlled drainage technologies does not automatically lead to GHG mitigation, guaranteed increased income or spontaneous adoption.

Although several studies have shown increases in crop yields can result from installing sub-irrigation with controlled drainage, these technologies have not been installed over a wide area and information on their economic impact with regards to their GHG mitigation potential is not readily available. Farmers' adoption of a new technology is significantly influenced by its economics and environmental impacts. Thus, the economic and environmental potential impact of installing sub-irrigation with controlled drainage technologies for the average farmer in Quebec is an important research issue.

1.2 PROBLEM STATEMENT

Global climate change is increasingly becoming a source of concern due to continuous increases in GHG emissions from various sectors including agriculture. Canada, a member of the UNFCCC, ratified the 2009 Copenhagen Accord and agreed to reduce its GHG Emissions by 2020. In agriculture, there are several methods by which GHG emissions can be mitigated in agricultural soils. Examples include implementation of innovative management practices like precision agriculture, no till, and WTM. Agriculture Canada through AGGP in partnership with the Brace Centre for Water Resource Management is carrying out research on various WTM systems to facilitate water use efficiency, reduce GHG emissions whilst sustaining crop yields. To accomplish the implementation or adoption of these technologies, farmers are the key agents. They play a vital role in ensuring that the farming sector engages in sustainable practices by adopting appropriate BMPs. The majority of farmers will be encouraged to adopt a new technology if it offers (or promises) economic gains or helps them become agricultural stewards of the land thus assuring environmental sustainability.

Under the AGGP, there were about six research sites where studies were conducted using innovative water management techniques and their GHG mitigation potential in vegetable production, grain production, and pasture. This study focuses on corn production in Quebec, Canada. This study seeks to evaluate the following questions:

(i) What will be the expected outcomes (economic and environmental impact) from adopting Controlled Drainage with Sub-irrigation technology from an on-farm (farmer) and off-farm (societal) accounting stance?

(ii) Contingent on the potential economic outcomes of this study will there be a need to make a case for policy changes? In other words, what institutional changes should be reviewed or implemented that would encourage the adoption of these technologies in the region; bearing in mind that most farmers are profit-oriented?

1.3 OBJECTIVE OF THE STUDY

In an attempt to find beneficial water management practices that mitigate agricultural GHG emissions (thus ensuring agricultural sustainability and improving environmental quality), this study aims to assess alternate water management technologies. The two alternative technologies are: conventional/tile/Field drainage (FD) and controlled drainage with sub-irrigation (CDSI). This study will estimate the most cost effective method of reducing GHG emissions for the farmer and public (society). More specifically, this study aims to evaluate the economic impact (i.e. benefits and costs) and simultaneously taking into consideration the environmental effect (more specifically, the GHG emissions impact) of adopting CDSI and FD from a private and public accounting stance.

1.4 STRUCTURE OF THESIS

Chapter two offers a review of earlier studies that have employed benefit cost analysis as a tool for evaluating economic and environmental impacts of implementing Beneficial Water Management Practices at the farm level. A brief overview of the methods used, including the economic foundations of the methods and a review of their potential weaknesses are presented. Chapter three provides details of the scope of the study and details regarding the analytical framework of costs and benefits from a private and public accounting stance; i.e., a Financial and Economic analyses of installing the new water management systems is described. Chapter four presents the results of the analysis. The concluding chapter presents the conclusions based on the analyses and offers the implications of the results. Lastly, a discussion concerning the limitations of this research and future potential research and recommendations are also suggested.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The subject of global warming and climate change has been at the core of several recent studies as researchers and scientists seek to understand this complex and inter-disciplinary issue and find ways of improving environmental quality and ensuring sustainability. In the move towards influencing the adoption of more sustainable management practices, researchers have to choose between alternate management practices by evaluating the impacts of these practices on the environment and the economy. Improving environmental quality will depend on implementing instruments that will make farmers accountable for the externalities from their management practices. Determining the value of the direct effects and externalities that a technology or practice may produce and its impact on environmental goods and services is at the core of this study, as it equips individuals and decision makers with insights into making sound judgments' that could influence the enactment of appropriate policies to improve societal welfare.

There are several methods available for achieving this task like multiple criteria analysis (Omann, 2000; Linkov et al, 2004), cost effectiveness analysis (Levin and McEwan 2001; Pearce et al 2006), and benefit cost analysis. For this study, benefit cost analysis is employed because it can be used to assess the effects of a technology from both a private and public (society's) accounting stance, providing decision makers with insightful information in establishing informed policies (Hanley and Spash, 1993; Townley, 1998; Zerbe and Bellas, 2006). Typically, farmers face net costs when implementing new practices while the benefits of a reduction in negative environmental impacts associated with the adoption of a new technology are given to society in general.

This literature review presents research findings on the relationships between crop production, water, GHG emissions and climate change. The main focus of the review is on the manner in which water management systems have been evaluated and the role played by technology adoption in achieving the goal of improved agricultural practices.

2.1.1 AGRICULTURAL GREENHOUSE GAS EMISSIONS AND CLIMATE CHANGE

As global population increases, food consumption is bound to increase, which implies a need for an increase in food production. Increased crop production per unit of land usually entails an increase in nitrogen (N) fertilizer use resulting in an increase of N availability in the soil. Additional N use through fertilizer and manure is associated with climate change through emissions of nitrous oxide. It is imperative that better management practices are considered to minimize the impact of agricultural production practices on climate (Verge et al, 2007).

Agriculture is a major source of emissions and an investment in agricultural research has shown the potential of providing GHG mitigating strategies. Agricultural research can provide insights that may lead to the development of GHG mitigation strategies that reduce emissions while improving crop yields. Increased yield implies an increase in crop intensification rather than an increase in area planted (See also, Adviento-Borbe et al, 2007) for effects of crop intensification on emissions); this must be combined with conservation practices to reduce agricultural Greenhouse Gas Emissions (GHGE). Similarly, mechanisms for linking investments in crop yield improvements to carbon markets should be studied (Burney et al, 2010).

Carbon dioxide (CO_2), Nitrous Oxide (N_2O), and Methane (CH_4) are the major GHGs emitted from agriculture. However, their impact on climate, measured global warming potential (GWP) is different, as supported by scientific investigators (Houghton and Callander, 1992; Hegerl and Cubasch, 1996; Ramanathan and Feng, 2009). The relationship between climate change and GHG emissions is complicated; Schneider (1989) reviewed atmospheric changes over 100 years and showed how climate changes interact with fluctuations in greenhouse gases.

Climate change, which is characterized by changing precipitation patterns, an increase in atmospheric temperature, rising sea levels, and extreme weather events will lead to changes in production practices (Seyoum-Edjigu, 2008). This will impact the distribution chain and consumption patterns for water (Wilcock et al, 2008), and affect the potential for land use changes (Nalley et al, 2011). Also, rapid climate change could cause slower forest absorption rates and a warmer climate could quicken the release of CO_2 from dry soils and CH_4 from rice paddies. Global warming has not followed a steady pattern because an increasing population, global consumption of fossil fuels and the rate of deforestation influence emissions and all these factors should be considered when forecasting emissions (Schneider, 1989).

Solomon et al (2009) showed that climate change caused by an increase in CO_2 concentration is largely irreversible for about a thousand years after emissions stop. Discount rates used in economic analyses, when forecasting emissions and reviewing mitigation strategies, neglect the irreversibility of CO_2 unique long-term impacts. This exacerbates the debate of the “correct” discount rate to use for environmental management projects. However, hyperbolic discounting may address this problem.

Uncertainty remains about the extent and time span of effects. It is important to fully understand the impacts of climate change in order to know when and to what extent policy should intercede in promoting responsible practices.

2.1.2 AGRICULTURAL GREENHOUSE GAS EMISSIONS, WATER AND CROP PRODUCTION

Nitrification is an aerobic process that occurs when there is sufficient oxygen in the soil to allow soil microbes to oxidize ammonium (NH_4+) to nitrate (NO_3-) and produce Nitrous Oxide (N_2O). De-nitrification occurs when soil oxygen is depleted or in wet soils. Soil microbes turn to nitrate (NO_3-) or nitrite (NO_2-) for respiration and then produce N_2 or N_2O (Nash, 1996).

Using principal component analysis (PCA) and principal component regression (PCR) to understand how soil management practices (specifically tillage and irrigation) and/or soil properties affect GHG emissions from soils, Lee et al (2006) found that irrigation or field moisture content in soils (See also, Liebig et al, 2005); Adviento-Borbe et al, 2007) for effects of high soil/air temperature and water content on CO_2 and N_2O emissions) had more effect on GHG emissions than tillage practice, i.e., conventional tillage and no tillage (see Maraseni and Cockfield, 2011) for effects of tillage practices on GHG emissions). Change in agronomic practices from dry land cultivation to irrigated farming has the possibility of GHG mitigation through higher sequestration of soil carbon (Eagle and Olander, 2012).

Also, soil biochemical parameters like microbial biomass, Carbon (C) and Nitrogen (N) available in the soil has a greater positive effect on emissions than soil physical properties, like soil texture or bulk density, and the effect on GHG emissions become more apparent after water was applied to the soil. A study in Australia concluded that irrigated maize production is one of the strongest sources of N_20 in crops and pastures systems, stating that increases in water content played a huge role in increasing GHG emissions. Conversely, it was suggested that there is considerable potential for mitigation through improved soil porosity, particularly when stubble is incorporated, which reduces the availability of inorganic nitrogen in the soil (Meyer et al, 2006).

Ng et al (2002) evaluated the effects of controlled drainage with sub-irrigation (CDSI) and conventional (tile) field drainage (FD) on a sandy loam soil in Southwestern Ontario to assess the impacts of CDSI on nitrate leaching and corn yields. They found that CDSI treatment resulted in an 11% greater water use efficiency (WUE), 21% higher soil moisture content than FD and a 64% yield increase in the CDSI treatment versus FD. Also, the nitrate concentration in drainage water was reduced by 41% in the CDSI treatment.

Some studies (Lal, 2004; Nalley et al, 2011) have assessed the impact of trading carbon-emitting permits to reduce GHG emissions. Using a Life Cycle Analysis (LCA) to estimate direct and indirect carbon emissions, these studies found that emissions trading could lead to emissions reductions. However, emission target reductions beyond 10 percent reduced carbon efficiency gains, reduced acreage in production, and reduced agricultural income unless commodity prices rise to counterbalance these outcomes. The study (Nalley et al, 2011) pointed out that secondary losses from inputs and processing industries, and transaction costs connected with enforcing emission restrictions and price-based incentives for practicing less carbon intensive practices could add to the negative aspects of emission reduction policies (Nalley et al, 2011).

Adviento-Borbe et al (2007) concluded that reductions in agricultural GHG emissions can be achieved through optimum management by selecting the right mixture of adopted varieties (e.g. soil C sequestration was higher in continuous maize than in maize-soybean rotations), planting date and plant population to maximize productivity and strategic water and nitrogen management practices that lead to nitrogen and water use efficiency to avoid N_2O emissions as well as crop residue management (Follett, 2001). Also, policies that support adoption of resource efficient management practices satisfy increasing demands for crops such as maize and soybean, and mitigate agricultural GHG emissions. Lastly, these management practices have mitigation potential as they often depend on the biophysical characteristics of the region.

2.1.3 CLIMATE CHANGE, CROP PRODUCTION AND WATER

Scientific studies (Bootsma et al, 2005; Tubiello et al, 2002; Southworth et al, 2002) reviewed the potential impact of future changes in climate, climatic variability and CO_2 on maize. The results showed that an increase in crop heat units (not exceeding 30^0) results in an increase in crop yields in North America. These estimates are based primarily on the effect of increasing temperatures on average yield as determined from field trials conducted under existing climatic regimes. This could lead to a substantial increase in land area allocated for maize and soybean production and land-use change policies.

There are numerous factors such as pests, diseases, direct effects of CO_2, plant breeding, soil fertility, management practices and socio-economic factors, which could affect future crop production under a changed climate (Manning and Tiedemann, 1995; Bootsma et al, 2005). Adaptive response to climate change by producers would also affect future changes in crop production. There has been little research done on the potential impacts of climate change on crop production in the Maritime region of Canada. Much work has been done in controlled environments to investigate the response of specific hybrids/cultivars to environmental conditions, which does not consider the impacts that changes in hybrid/cultivars can have under a changed climatic regime. For example, a shorter grain-filling period at higher temperatures have been associated with lower grain yields in corn (Hunter et al, 1977; Badu-Apraku et al, 1983; Muchow et al, 1990), suggesting that climate warming will result in lower corn yields at higher temperature.

While some studies such as Ng et al (2002) believe that the "win-win" scenario of reduced GHG emissions and water use efficiency can be achieved, other studies such as Mushtaq et al (2013) propose that there would be a need for a trade-off as modern irrigation technologies may cause increased on-farm energy consumption and GHG emissions (See also, Schlesinger, 1999; Mosier et al, 2005; Maraseni and Cockfield, 2011), leading to potential divergences in terms of mitigation and adaptation policies. They proposed that an integrated approach should be used to avoid potential conflicts when formulating climate change mitigation and adaptation policies.

2.2 WATER

In the past decades, water was viewed as a public good due to its characteristics, making it difficult to value and thus consequently to price. However, in light of current water scarcity challenges brought about by climate change, a need has arisen to price water in order to appropriately represent its scarce nature (See, Brown, 2006; Siebert et al, 2007 for water scarcity issues and water use) and in a bid to engender sustainable use.

Water prices affect the demand for water and employing irrigation systems with higher water use efficiency (WUE) outputs will cause farmers to gravitate towards these systems. However, water use will be discouraged if prices are high leading to reduced irrigation use and in turn reductions in crop productivity, farm income and a long run detrimental effect on agriculture (Gomez-Limon and Riesgo, 2004). It is important to note that world population is on the rise, so are food demands thus, a reduction in crop productivity could have adverse effects on the world population. Valera-Ortega et al (1998) noted that water demand responses to prices were elastic within a certain range and farm practices did not change significantly within certain regions in the short term.

There are several components to consider when assigning water prices and water property rights, to ensure that its scarcity is reflected in the price. Lui et al (2009) undertook a study in China and suggested the use of the shadow price of water to assign its value. Colby (1989) used alternate uses of water to estimate value i.e. opportunity cost of water, while Kulshreshtha and Tewari (1991) used the derived demand function approach. Pricing methods include block rate, Input/output, and volumetric amongst others (Tsur, 2005). Johansson et al (2002) and Rogers et al (2002) pointed out that water policy choices largely depend on physical, local, political, institutional and social conditions as well as knowing the full-cost of water. All these are key factors when formulating water policies. Caswell and Zilberman (1985); Moore et al (1994) and Garrido et al (1997) concluded that water-pricing policies coupled with adoption of modern irrigation technologies could lead to significant water savings.

2.2.1 IRRIGATION

Irrigation in this study refers to both the removal (drainage) and application of water to agricultural lands to enable a favorable environment for plant growth and development. Water scarcity problems and the need for improved crop yields gave birth to irrigation (Numerous studies discuss the importance of irrigation. See for example, Walker, 1989).

There are different classifications or categories of irrigation (See Burt et al, 2000; Brouwer et al, 1988; Ali, 2011). A common classification is surface, subsurface, sprinkler and drip Irrigation. Drainage systems on the other hand are usually distinguished into two: surface or subsurface drainage systems.

There are several types of irrigation methods in most categories. In order to know which type is most suitable for a certain crop type, numerous factors come into play. Researchers and producers have to determine how much irrigation water to apply by estimating the efficiency of the irrigation system. The efficiency can be measured at different scales but whatever measurement scale is chosen, it is critical that it matches with specific objectives (Ali, 2011). Some efficiency parameters or performance indices, used in assessment or comparison of irrigation systems include: engineering (i.e. reasonable installation, design and maintenance requirements), field water use (i.e., increased water use efficiency Elfving (1982), Amosson et al (2011); crop and water productivity and acreage (i.e., improvement in soil profile and crop yields (Evans and Sadler, 2008) advocate for drip irrigation system); and socioeconomic indicators (i.e. change in farmers' income). To achieve the most benefits, it is important to use irrigation technologies in combination with sound agronomic practices and adherence to design installation and requirements (Rogers and Lamm, 2009).

While, various regions require irrigation (i.e. application of water to the soil) for crop production, others require drainage (i.e. removal of water from the soil). Example of areas requiring drainage include the humid regions of eastern Canada, and the eastern and mid-western United States. In Quebec, subsurface drainage is practiced on over 735,000 ha of farmland (Gollamudi, 2006). Some of the most productive lands in the world are drained lands (Wright and Sands, 2001).

Beyond higher crop yields and water use efficiency there are issues of water run-off to watersheds causing pollution due to nitrate leaching concentrations, and other effluents.

These lead to a host of concerns including an increase in GHG emissions and ultimately leading to water scarcity (Heathwaite et al, 1990; Cooper et al, 1992; Sharpley et al, 1994; Ongley, 2004; Gao et al, 2012; Lu et al, 2015). Therefore, there is a need to optimize drainage systems in order to improve crop yields, control and manage run-off to watersheds and reduce the incidence of greenhouse gas emissions. This has led to an interest in Water Table Management.

2.2.3 WATER TABLE MANAGEMENT

Water Table Management (WTM) can be described as the process of regulating soil moisture content for optimum crop growth. There are three main types of WTM, tile/conventional drainage, controlled drainage and controlled drainage with subsurface irrigation. These water table management systems can be viewed as successive improvement over the previous technology with controlled drainage with subsurface irrigation being the latest upgrade.

Water table management has several benefits which include but are not limited to; it increases water storage capacity in the soil profile, improves soil physical properties, brings about a significant reduction of nitrate concentrations in tile drainage outflows, and increases crop yield (Hundal et al, 1976; Madramootoo, 1990; Madramootoo et al, 1992; Skaggs et al, 1995; Amatya et al, 1998; Mejia and Madramootoo, 1998; Zhao et al, 2000; Busman and Sands, 2002; Stampfli and Madramootoo, 2006). It improves the off-farm water quality, enhances water use efficiency, reducing water losses to unusable sinks, reducing water degradation and reallocates water to higher priority uses (Howell, 2001).

Irrigated agriculture without adequate management can be detrimental to environmental quality and jeopardize sustainability efforts because of inefficient use of inputs (water, fertilizer and labour) leading to nitrogen leaching into water bodies, soil salinity hazards and ineffective institutions (Madramootoo et al, 1992; Howell, 2001; Khan et al, 2006). Similarly, water table management has increased peak flows in some cases (Konyha et al, 1992). Therefore, to ensure increased crop productivity, maximize the use of agricultural lands and enhance sustainability, the efficient use of water has to be combined with beneficial management practices.

The technology of interest in this thesis is Controlled Drainage with Subsurface/Sub-irrigation (CDSI) technology. It is viewed as a beneficial management practice because it has the potential to improve crop yield and water use efficiency, although it was not clear in some studies that the benefits can offset the investment costs. This study focuses on Controlled Drainage with Sub-irrigation with its GHG mitigation potential as an additional benefit. Figure 1 below shows a brief pictorial presentation of the three WTM systems showing briefly how they function.

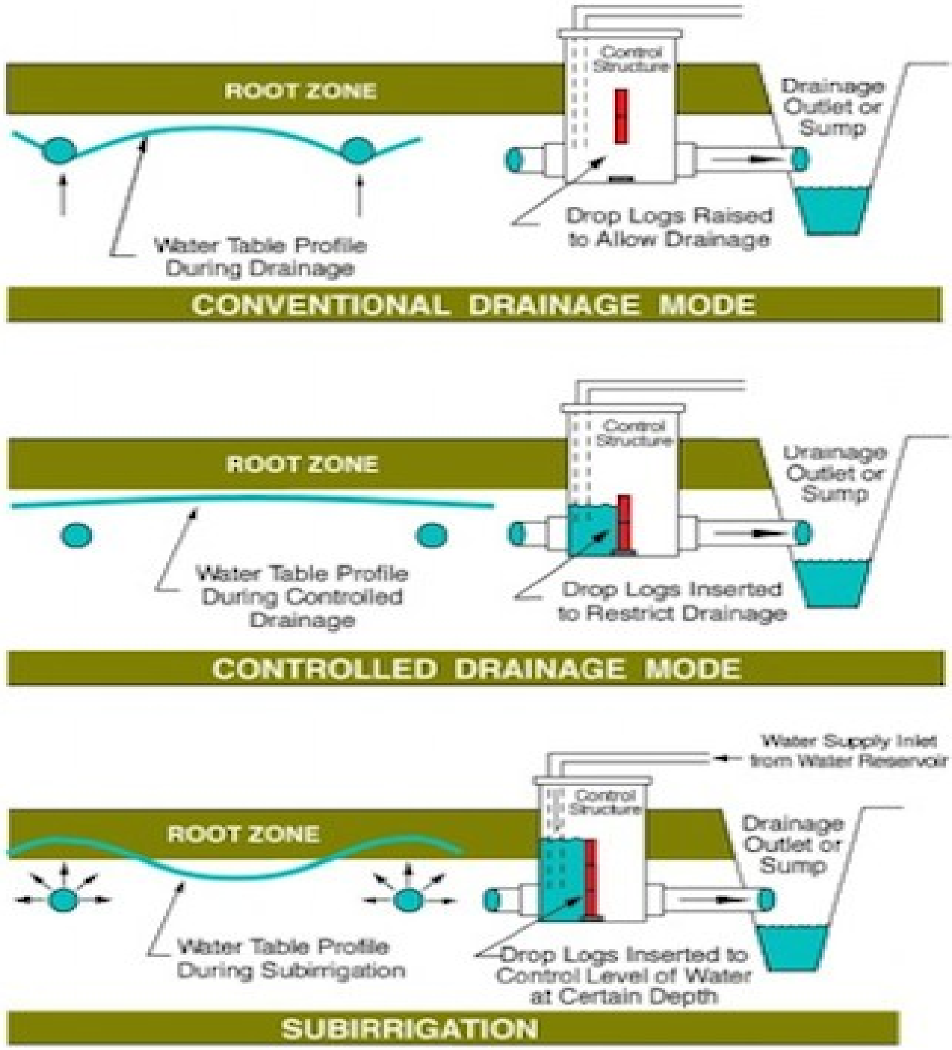

Figure 1 Modes of Water Table Management (Singh, 2013)

2.2.4 CONTROLLED DRAINAGE WITH SUBSURFACE/SUB-IRRIGATION IRRIGATION TECHNOLOGY

The CDSI system is a combination of controlled drainage with sub-irrigation. Controlled drainage operates when a control structure is used to conserve water by regulating flow but no additional water is supplied, while sub-irrigation is the addition of water to the soil through the controlled drainage pipes. When precipitation exceeds the amount of water required by the crop, sub-irrigation is stopped and the system acts like a drainage system and excess water is drained from the field. In regions with inadequate precipitation or during drought, controlled drainage systems (CDS) would be unable to store enough water for crop growth. Controlled drainage reduces short-term stress. Sub-irrigation technology is relatively new but, in recent times, there has been an increased interest in undertaking related research (Lamm et al, 2012).

The CDSI system has the potential to increase water-use efficiency, irrigation efficiency, and crop yields (Doty et al, 1983; Nemon et al, 1987; Madramootoo et al, 1992; Tait et al, 1995; O'Brien et al, 1998). Controlled drainage can reduce nitrates in drainage water by over 46% (Willardson et al, 1972; Steenvoorden, 1989; Madramootoo et al, 1993; Lalonde et al, 1995). However, there are some potential challenges with controlled drainage with sub-irrigation technology which include: investment costs are relatively high, water supply and system capacity problems because CDSI requires a constant and steady water supply, increased labour requirement, inflexible design and emitter clogging (Payero et al, 2005; Enciso et al, 2007). The water should be free of sediments, chemicals, and biological compounds to ensure the longevity of the pipes.

It is important to note that it is uneconomical to use sub-irrigation if only irrigation is required with no need for drainage (Nyvall, 1998). Sub-irrigation systems apply water directly to the crop root zone through buried pipes. Small holes known as emitters are usually spaced every few inches along the pipes. During irrigation water goes through the emitters to the soil, its movement and wetting pattern usually depend on the soil characteristics. Figure 2.2 below shows a pictorial description of how water table management operates under sub-irrigation mode.

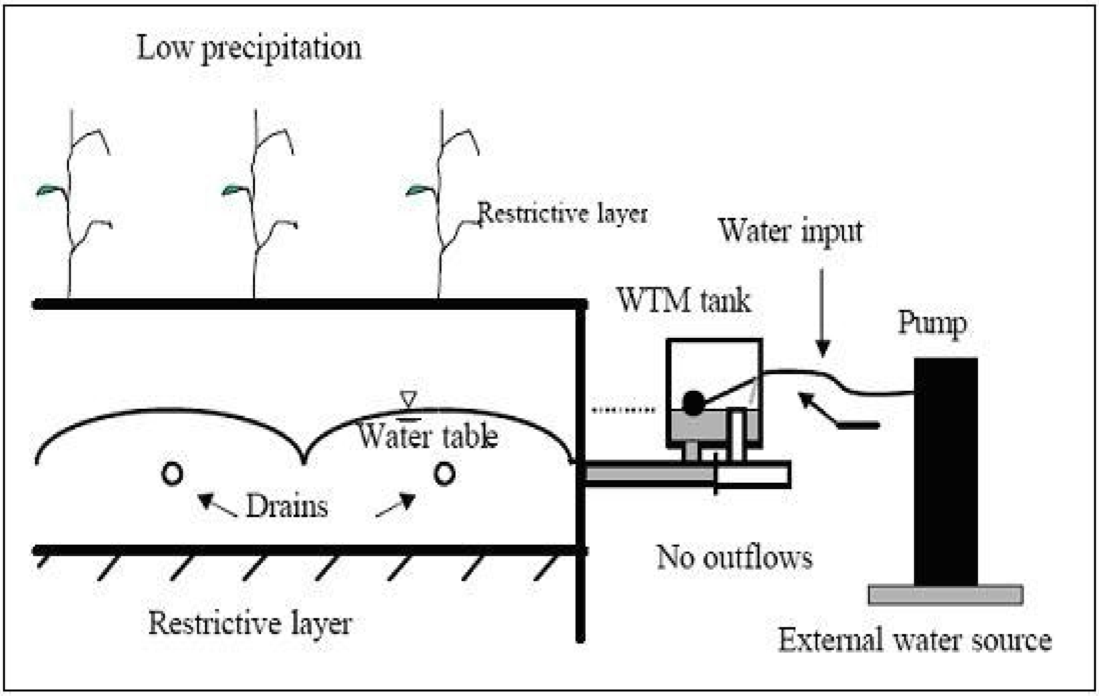

Figure 2 Subirrigation mode (Stampfli, 2003)

Irrigation requirements vary from one location to the other due to differences in biophysical characteristics, as well as by crop type and depend on farm management decisions. However, some questions are similar for all irrigation systems when deciding which irrigation system to choose, such as when to irrigate, how much to apply, and can the efficiency be improved? The following section briefly discusses these irrigation efficiency assessment parameters.

2.2.5 SELECTION REQUIREMENTS FOR IRRIGATION EFFICIENCY

The factors to consider when selecting an irrigation system, with a focus on CDSI requirements, are grouped into engineering, field water use, crop and water productivity and acreage, biophysical characteristics, socio-economic and environmental indicators (Walker and Skogerboe, 1987; Ali, 2011) with a focus on CDSI system requirements. These parameters are used to compare various irrigation systems in order to choose the most suitable system for a certain crop in a certain location.

Engineering Efficiency Parameters and Field Water Use

Engineering efficiency parameters comprise factors to consider when assessing system design such as; water table control structures (e.g. flashboards and float type), sizes of pipes, and depth of pipes, pipe spacing, water balance, and irrigation scheduling. Several studies have compared the effect of various irrigation systems to assess its water use efficiency, irrigation frequency, lateral spacing and installation depth. For example, Enciso et al (2005) compared the effect of lateral spacing and installation depth on cotton yield with subsurface drip irrigation on a clay loamy soil. Results showed higher yield with greater installation depths (i.e. 0.3m instead of 0.2m) however, yields as a result of different lateral spacing were inconclusive. Several studies (Powell and Wright, 1993; Caldwell et al, 1994; Khan et al, 1997; Lamm et al, 1997, 2010; Fouss et al, 1999) investigated the installation depth for corn production on average and they recommend between 0.25m-0.45m depending on the soil type. Similarly, for lateral spacing for corn, these studies recommended a spacing of about 1.5m depending on soil type.

Hanson et al (2003) investigated the effect of irrigation frequency on the vegetable yield on a sandy loam and silt loam soil and found that drip irrigation frequencies of once per day or twice per week were suitable in medium to fine texture soils for that soil and climate. Lamm and Aiken (2005) also studied the effect of irrigation frequency on corn yields on a deep silt loam soil and found that there was no significant impact in this soil type. However, Payero et al (2008) studied the effect of irrigation frequency on corn yields in the semi-arid region of Nebraska and found a significant increase in yields (by 22% in

2005 and 52% in 2006). Also, Badr et al (2010) investigated the effect of type of irrigation and the irrigation levels on potato production on a sandy soil and found that reduced water application levels reduced yields significantly.

Mejia et al (2000) investigated the effect of water table controls of sub-irrigation on corn and soybean yields with controls at 0.50m and 0.75m from the soil surface, both corn and soybean yields were higher by 13.8% and 2.8% respectively, compared to the conventional drainage system. It is important to note that narrower drain spacing allows for better water table control (Madramootoo et al, 1993). This would imply that more pipes would need to be installed per acre or hectare e.g. in a hectare of land, with 30m drain spacing, total pipe length required is about 330m and in 15m drain spacing pipe length required is 670m leading to an increase in investment costs (CRAAQ, 2010).

Some other selection indices include uniformity of irrigation system, longevity, installation and water use efficiency (See Camp, 1998 review). Lastly, some design components of sub-irrigation system are not flexible once installed like Dripline diameter, and spacing and depth. Consequently, it is essential that the farmer and water table management expert make the decisions together.

Biophysical Characteristics (Crop and Water Productivity)

When selecting a water management system, beyond the engineering design and installation requirements, it is important that the system chosen is compatible with the crop type and existing farming operations, recognizes water availability and the biophysical characteristics (e.g. climatic conditions, soil physical and chemical properties, and topography) inherent in the region. Sub-irrigation technology requires a topography that has a slope of less than 0.5%, so that some crops do not suffer from flooding whilst other crops on the same field have insufficient water supply. When deciding on the installation depth and lateral spacing, as seen above the soil type plays a large role in choosing the depths and drain spacing, soil texture, soil water-holding capacity, which determines the hydraulic conductivity and the way the water spreads.

Weather conditions play a major role as well because whilst some crops require irrigation, the same crop may require drainage in a different region for optimum productivity. Water quality and quantity for irrigation plays a huge role when choosing a system because the source of the water affects the costs and the quality of the water available affects crops and irrigation system. The crop type is a very important factor when selecting an irrigation system because all the improvements are geared towards improved yields for the farmer and a sustainable environment for society through nitrogen use efficiency, water use efficiency and more recently, greenhouse gas emission reduction potential.

Hiler and Howell (1973) studied five water treatments including subsurface irrigation and found that the sub-irrigation system was not the most efficient in terms of crop yield and water use efficiency. Although various studies (Lamm et al, 1995; Steele et al, 1996; Drury et al, 1993, 1996; Lamm et al, 1997; Tan et al, 1999; Mejia et al, 2000; Ng et al, 2002; Lamm and Trooien, 2003; Payero et al, 2008; Luo et al, 2010; Bonaiti and Borin, 2010) investigated the effect of controlled drainage with/without sub-irrigation on crop yields (mostly field crops like corn), nitrogen use efficiency and water use efficiency and found CDSI to be the most efficient system. Tan et al (1999) found that CDSI on a sandy loam soil in Ontario increased corn yields by 64% compared to conventional drainage.

Despite the fact that an irrigation system satisfies engineering efficiency indicators and biophysical efficiency parameters, it does not guarantee that it would be economically feasible. Thus, the economic performance of an irrigation technology is an important component in the decision or selection process because it determines if the farmer would adopt a given technology. Consequently, the section below focuses on how economic and financial indicators affect adoption of irrigation technologies. A sub-irrigation with controlled drainage system has a higher investment cost than conventional drainage. However, it has the potential for higher yields and yield uniformity is improved within a field as the crops receive similar moisture because CDSI corrects topography as well as between years as water is supplied to crops in dry years. An important question is therefore; will the return on investment from the CDSI system justify the cost?

2.3 ECONOMICS

A logical selection process would require that the irrigation technology satisfy the engineering and biophysical characteristics' irrigation efficiency parameters before proceeding with an economic analysis. This ensures that the technology does not satisfy technical efficiencies at the expense of economic feasibilities (Magwenzi, 2002). The economics of irrigation technology assesses how an irrigation system causes changes in production inputs and outputs. Several indices are considered; water availability and quality, water prices, irrigation system costs, such as investment, installation costs (which will include land preparation when needed), operation and maintenance, crop type and market prices, increased labour demand, and energy costs (Caswell and Zilberman, 1985; Brouwer et al, 1988; Crabbe et al, 2012).

2.3.1 FARMER PERSPECTIVE

Farmers are more likely to adopt irrigation technologies that enable them to increase their profit relative to the situation prior to the investment when there is available financing to support the initial investment (Wichelns, 2007). There are several economic models used to compare irrigation technologies. Several studies use Net Present Value (NPV) analysis to compare between alternate technologies (Hall et al, 1985; Henggeler et al, 1996; O'Brien et al, 1998; Magwenzi, 2002; Lamm and Aiken, 2003).

Several studies (Bosch et al, 1992; Cooper et al, 1992; Drury et al, 1996; Fisher et al, 1999) provide economic results of the effect of sub-irrigation on crop yields. Carreira et al (2006) used a dynamic optimization model and found that a subsurface drip irrigation system had higher expected net returns than a centre pivot sprinkler irrigation (CPSI) system. Nistor and Lowenberg-DeBoer (2007) noted that there is not an abundance of available published literature investigating the economic analysis of controlled drainage on crop yields and the profitability of controlled drainage with sub-irrigation technology as one system.

Using the Purdue Crop/Livestock Linear Programming (PCLP) model to compare two enterprises (corn-soybean rotation with and without managed drainage scenarios) Nistor and Lowenberg-DeBoer (2007) showed that the "with" managed/controlled drainage scenario gave the best solution by about 10% when compared with field drainage. Also, Evans et al (1996), Brown (2006) and Crabbe et al (2012) indicated that controlled drainage would increase potential yields by 10% to 20%, 1.4% to 13% and by approximately 4% respectively, compared to conventional drainage. However, Tan et al (1999) results in Southwestern Ontario showed a minor soybean yield benefit for controlled drainage under conventional tillage but a slight yield decrease with no-till. However, neither of these yield differences was statistically significant. The slight decrease in yield can possibly be attributed to the increased drainage water and nitrate loss observed under no-till.

On the other hand, Dhuyvetter et al (1995) [cited in Camp (1998)], reported that benefits achieved from the sub-irrigation system were not sufficient to offset the high investment costs involved in installing and operating the system even though the system had higher yields, increased residual land potential, increased water saving potential and wetland mitigation payments. Using a partial budget approach, Heard et al (2012) results suggested that if there is a significant increase in pasture consumption, valued at $300/t DM (tonnes of dry matter per hectare), with simultaneous water savings of 2.0 ML/ha/yr, valued at $250/ML, every year for 10 years, then the internal rate of return (IRR) is large enough to offset the cost of the Subsurface Drip Irrigation system for grazed perennial pastures.

Most of these gains in Subsurface Drip Irrigation (SDI) or controlled drainage are achieved through increased yields, or a decline in production costs, such as electricity costs, labour costs, and fertilizer application through increased efficiency. Hanson et al (2003) and Namara et al (2007) studies showed that installation of SDI resulted in an increase in water use efficiency and water savings. Smith and Maheshwari (2002); Connor et al (2012); Bhaduri and Manna (2014) have indicated that in regions with irrigation water scarcity or high water prices, this water saving benefit brings about an increase in net returns to the farmer. Also, some studies showed a change in economic outcome depend on field size (See Bosch et al, 1992; Lamm et al, 2012), system life (O'brien et al, 1998; Carreira et al, 2006), initial investment cost (Lamm et al, 1997; Hillel, 1997), crop type and crop price (Delano and Williams, 1997 cited by O'Brien et al, 1998; Namara et al, 2007; Narayanamoorthy, 2010) for the same irrigation technology.

Lastly, (Knapp, 1993; Camp, 1998; Payero et al, 2005) recommended that irrigation systems depend on physical, biological and economic factors, which should be considered before installing sub-irrigation with controlled drainage technology. They recorded yield gains for fruit and vegetable crops and noted that interest in the system is gaining ground but it is important to obtain farmer and expert information within your region that have already implemented these systems to aid in the decision to invest.

O'Brien et al (1998) noted that even though corn yields were higher under SDI (Subsurface drip irrigation) than CPSI (Centre Pivot Sprinkler Irrigation), SDI fixed costs were quite high, resulting in lower net returns. For CPSI, only part of the field was used for irrigated corn, the other part of the field was cropped to non-irrigated wheat. CPSI had a higher net return advantage than SDI on larger fields due to lower per hectare investment costs for larger CPSI systems. For a 13ha field, SDI returns were higher because CPSI required large increases in per hectare investment costs for the smaller fields.

Similarly, Lamm and Aiken (2003) recorded that CPSI had a system advantage of $59/acre on 125 acres while SDI had a loss of $56.61/ha on 51.4 hectares (127 acres) compared to CPSI, observed in the study by O'brien et al (1998). Furthermore, the study mentioned that CPSI systems were sensitive to the size and the shape of the system, with advantages favouring larger CPSI systems over SDI systems, whereas the longer life of the SDI system was advantageous as it increased net returns over CPSI systems. Carreira et al (2006) compared CPSI and SDI by maximizing the expected utility of the stream of net farm revenue to fully integrate inherent risks of farming with inadequate rainfall, ammonia volatilization, and limited freshwater over time. The 100year production horizon was considered to give adequate time to account for aquifer depletion. Over the 100year time period, the estimated difference between the two systems was about $40,000 and some producers may not be willing to change their irrigation system based on this difference.

Table 1: Summary of four Economic Comparisons of irrigation systems

Author	Methodology	Location	Crop	Field Size/years	Returns	Sensitivity Analysis
O'Brien et al, 1998	Partial Budgeting Approach to Compare SDI and CPSI i.e. (SDI-CPSI)	Western Kansas	Corn	64.8 ha	-$54.24/ha	Increase in Crop yield & price favours SDI and system life above 10yrs
				51.4 ha	-$56.61/ha	
				38.5 ha	-$42.16/ha	
				25.9 ha	-$2.36/ha	
				13.0ha	+$27.77/ha	
Carreira et al, 2006	Stochastic Dynamic Optimization model to compare SDI & CPSI	Texas	Corn	85yrs (SDI)	$512,026/155 acres	Higher crop yield over time & SDI conserves more nitrogen
				100yrs (CPSI)	$474,448/126 acres	
Lamm and Aikens, 2003	Partial Budget Approach to compare SDI and CPSI	Kansas	Corn	125ac	+$59/acre	System life & additional cost savings with SDI
Nistor & Lowenberg-DeBoer, 2007	Purdue Crop/Livestock Linear Programming (PCLP) Model to Compare Controlled drainage and Conventional drainage		Soybean- Corn rotation	With EQIP payments	+$66,789/150 0acres	Fuel and Nitrogen Price increases favours controlled drainage still.
				Without EQIP payments	+$49,614/150 0acres	

2.3.2 PUBLIC PERSPECTIVE

Whilst the farmer's goal in choosing between alternate technologies is assumed to be profit maximization, the social or government objectives for examining and encouraging beneficial management practices is to increase agricultural productivity, boost farm incomes, and generate greater public net benefits at the same time as ensuring sustainability. Due to the externalities brought about by agronomic practices, particularly irrigation practices, to the atmosphere, drainage water quality, nutrient loading in tile effluent and water quality in watersheds, water table management practices have evolved from crop productivity concerns to become a method for environmental control (Doty et al, 1983; Drury et al, 1996; Mejia and Madramootoo, 1998; Elmi et al, 2000 Madramootoo et al, 2007). Camp (1998) mentioned that several reports discussed the potential for a reduction of off-site environmental effects from installing sub-surface drip irrigation, however, none of the studies presented any evidence to support the inference.

National policies on foreign exchange, water-pricing policies, international policies on configuration settings of an irrigation system, support for certain sectors in a local economy, availability of system components or sufficiency in particular industries, could dictate which type of irrigation system should be adopted. Also, public policies and programs will be vital to encourage irrigation adoption. These often include providing subsidies, investing in research to develop less expensive irrigation technology options, and improving agronomic practices that enhance profitability and encourage sustainability.

The push to develop and implement agricultural systems that promote a reduction in GHG emissions has led to an emergence of carbon markets in North American. Nalley et al (2011) estimated GHG emissions from six crops produced in a region in the US using approximately 50 different production practices and a Cap and Trade System for carbon trading. A baseline case of emissions was estimated and hypothetical reductions of 5, 10, and 20% were levied on agriculture. The results indicate that a 5% reduction of emissions from the baseline case with present production practices enhanced GHG emission efficiency. A 10% reduction in GHG emissions from the baseline carbon footprint resulted in the efficiency gains being reduced but still remaining positive. However, for the 20% reduction, the result is a major change in cropping pattern with a substantial decrease in traditional crop acreage income and GHG emissions efficiency.

Another study (Weersink, 2002) recommended that a suitable policy to increase environmental performance of agriculture should involve a benefit-cost analysis. He argues that no single policy decision emerges as the ideal choice without conducting a thorough economic analysis. Therefore, environmental policies in Canadian agriculture will continue to involve searching for the mix of instruments to reduce negative environmental impacts.

2.4 AGRICULTURAL TECHNOLOGY ADOPTION

Previous literature has shown that because a technology provides financial, economic and environmental benefits, there is no guarantee farmers would adopt it. This is because other factors can cause a lack adoption since this decision is complex and multi-faceted (Doering et al, 1999). The following section reviews factors that affect adoption rates, including if a technology will be adopted completely, partially or not at all.

2.4.1 ADOPTION DETERMINANTS

Several Studies (see Knowler and Bradshaw, 2007 and Prokopy et al, 2008 for a synopsis of conservation adoption studies) have identified some of the following; farmer and farm characteristics (Lamba et al, 2009; Saltiel et al, 1994), social networks, financial constraints, perceived economic benefits of the technology (Cary and Barr, 1992; Saltiel et al, 1994) as factors that affect agricultural technology adoption. Other factors include; knowledge of how the technology operates effectively, awareness and perception of advantages, compatibility and observability of the technology (Reimer et al, 2012) as well as environmental awareness and perceptions (Kulshreshtha and Brown, 1993; Traoré et al, 1998). When carrying out an adoption study, disseminating technology information appropriately plays a huge role in informing farmers of the practices (Reimer et al, 2012). Additionally, policy interventions can be used to influence adoption of beneficial management practices but they usually depend on the type of technology, markets and the nature and duration of the policy involvement (Feder and Umali, 1993).

However, other studies (Knowler and Bradshaw, 2007; Prokopy et al, 2008 and Reimer et al, 2012) concluded that a more thorough synthesis of adoption studies indicated that there are few if any impacts that affect adoption universally. Also, Florax et al (2002) argued that more studies may not lead to better insights, as there may be diminishing marginal benefits caused by redundancy. Therefore, efforts to promote sustainable agricultural practices will have to be tailored to reflect the particular conditions of individual locations.

Data on determinants of adoption are usually gathered through surveys and/or interviews and are analyzed qualitatively (e.g. grounded theory) or quantitatively (e.g. binary regression analyses; Tobit, Logit, Probit analysis). Prokopy et al (2008) reviewed 55 cases of actual adoption studies (as there is a difference between acceptable and adoption, Reimer et al., 2012) over 25 years and found that the kind of statistical analysis used in the studies had a negligible effect on the results. Several irrigation adoption determinant studies (examples of studies include: Kulshreshtha and Brown, 1993; Moreno and Sunding, 2003; Abdulai et al, 2011) use Probit Regression as the assessment tool because it measures the probability (i.e. for every given unit change in independent variable) of adopting the technology and can be estimated using Maximum Likelihood Estimation (Davidson and Mackinnon, 2004 provide a detailed guide). Although some studies (He et al, 2007; Namara et al, 2007; Getacher et al, 2013) use the Logit regression model as it is a suitable method to use for larger sample sizes.

Adoption studies are often viewed from a top-down approach; i.e. from scientists or researchers to extension agents and then farmers. When farmers show reluctance or resistance towards a "new" technology, they are viewed as being laggards who may become late adopters or non-adopters. There are some rational barriers that prevent or delay adoption such as: conflicting information, unsuitability with aspects of farm management and personal objectives [all farmers do not have profit maximization as their goal; See Boehlje and Eidman (1984) for farm objectives], complexity, implementation costs and capital outlay (Vanclay and Lawrence, 1994). Their study (Vanclay and Lawrence, 1994) assesses the effectiveness of traditional extension practices and concludes that practices which are designed to be adopted by farmer's but fail to consider the farmer's subculture, and the rural elite may get results that truly represents their preferences or inclinations for a certain technology.

Prokopy et al (2008) observed the need for more research on determinants of adoption of water management practices, including the role played by tenure and farm proximity to natural water sources in affecting adoption decisions. They also noticed that very few studies paid attention to sustained adoption over time. Dinar and Yaron (1992) estimated the adoption and abandonment of irrigation technology and used the technology cycle to estimate the year of discontinuance.

In a more recent study, Rogers and Lamm (2009) found that farmers willingly adopt beneficial irrigation practices if they can recover the initial investment costs. They went on to emphasize that producers ought to thoroughly understand the design, operation and maintenance requirements of the irrigation technologies, specifically subsurface irrigation systems, before installation. This is because although it may be a viable investment option, it usually requires a considerable initial financial commitment and attention to detail when installing. Finally, adoption is increased when a practice can offer more than one benefit to the farmer and when it generates both private and public benefits (Wichelns, 2007).

2.4.2 RATE AND DEGREE OF ADOPTION

Bjornlund et al (2008) studied the rate of irrigation technology adoption in the Raymond and Taber districts of Alberta and found that the adoption rate varied between the two districts. Taber farmers, who were more economically viable and less dependent on off-farm work, had a longer farming family history, more secure water supply, and smaller farms adopted the technology at a faster pace than the Raymond farmers. They also found improvement in crop yields as a motive for the adoption of irrigation technologies, which is consistent with previous literature. Some studies have shown that survey participants ranked a cash subsidy as the first choice amongst others as an incentive to adopt. Lamba et al (2009) suggested that availability of financial incentives might instigate adoption of Beneficial Management Practices (BMPs).

However, Colman (1994), and Dobbs and Pretty (2004) argue that most farmers practice stewardship to some degree hence, policy options that proffer monetary rewards should not undermine farmers' commitment to environmental stewardship. Hence, farmers may willingly choose to invest (without government incentives) in technologies that engender environmental sustainability as long it does not reduce net farm income.

Simple and comprehensive information, farm size (See, Khaledi et al, 2010), input and output prices, confidentiality and cultivation of trust and confidence are factors that determine continuous or complete participation in a practice or technology (Dinar and Yaron, 1992; Smithers and Furman, 2003). Thus, an on-going challenge for researchers is to assess and document specific economic and environmental benefits associated with each beneficial management practice. This is important because adoption determinants, rates, degree, policy instruments, and impacts differ from one region to another.

CHAPTER 3

SCOPE OF STUDY AND METHODOLOGY

3.1 SCOPE OF STUDY AREA

Canada is a major corn-producing nation and is amongst the top corn producers worldwide. In 2012, Canada produced over 13 million MT of corn on an area of over 1.2 million ha. During the same year, about 872 million MT of corn was harvested worldwide from 170 million ha (FAO, 2013). Corn is the third largest crop in Canada (after wheat and canola), and the most important crop in Eastern Canada (Pattey and Jégo, 2010). Increased corn production in the world markets is probably responsible for the recent slump in global corn prices on the supply side, while both a reduction in the North American cattle herd and pig production are probably responsible for the decline in prices on the demand side. Corn market expansion may be due to the emergence of alternative uses for corn, which could help stabilize future prices (FAO, 2014).

Québec makes significant contributions to Canadian agriculture production owing to its relatively mild temperature and fertile soils. Statistics Canada (2007) estimated the number of farms in Québec and Ontario to be 29,437 and 51,950 respectively, accounting for 39.6% of Canada's 205,730 farms. These farms contribute significantly to farm receipts in Canada (CRAAQ, 2014; OMAFRA, 2014). As Canada continues to grow and develop, growing urbanization has reduced the number of farms and farm operators to 4.0% in Quebec, whilst the average farm size in Canada increased by 6.9% from 296 to 315 hectares in the five years to 2011 (Statistics Canada, 2011).

On average, Canadian farms engage in conservation tillage practices. Recent census data shows that 72% of the total land prepared for seeding in Canada is under some form of conservation tillage or no-till practice (Statistics Canada, 2007). Hence, Quebec farmers appear to be agricultural stewards. The experimental fields, of interest to this study, are located in St. Emmanuelle, Moneteregie, Vaudreuil-Soulanges, Quebec. These fields were used for the estimation of GHG emissions and cop yields with various irrigation and drainage systems. AGGP project fields were prepared by disking which only disturbs the top few centimeters and is considered conservation tillage.

Nitrogen (N) is an essential component of crop fertilizers as it improves crop yield; with corn accounting for 16% of the total fertilizer use and 17% of the world total nitrogenous fertilizer use (Heffer, 2009, FAO, 2013). Higher nitrogen application or higher nitrogen use efficiency increases corn yield; however it also creates health and environmental hazards when nitrogen leaches out to rivers and lakes (Madramootoo et al, 1992). This is because high nitrate content in drinking water may cause health disorders (Gelberg et al, 1999).

Corn does well on a wide variety of soils, but performs best on silt loam soils that are well drained, in good tilth, and free from erosion. Early-planted corn has fewer disease and insect problems, and therefore, it generally out-yields late-planted corn. The soil type in St. Emmanuelle, is a Fine Sandy Loam soil (Mejia et al, 2000). The farm lies in the St. Lawrence lowlands and the experimental field is 4.2ha in area. The farm is located in Coteau du lac, Monteregie, Quebec about 25km southeast of McGill University Macdonald Campus. The field has a flat topography with an average slope of less than 0.5% (Kaluli, 1999). Figure 3 below shows the location of the farm.

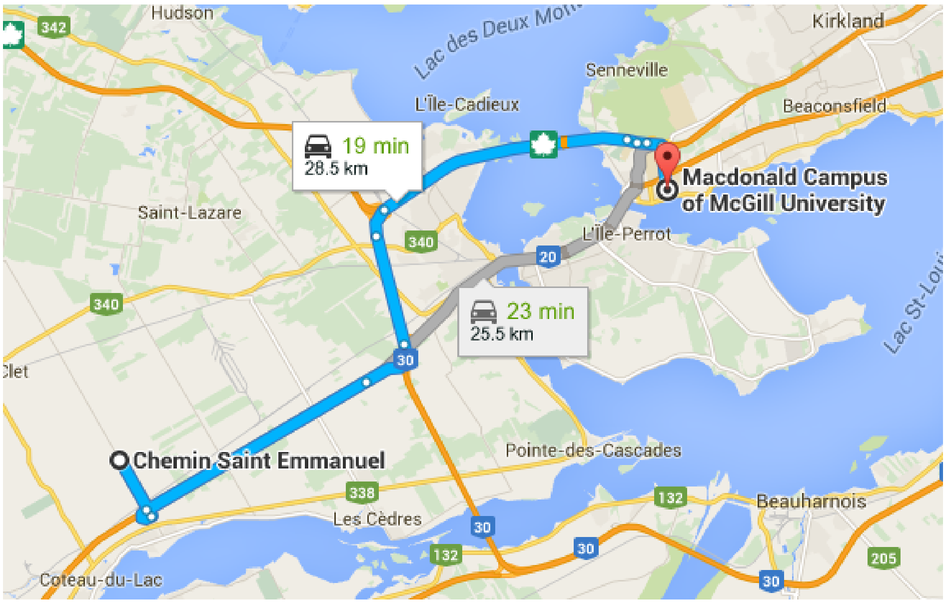

Figure 3 shows directions from McGill University, Macdonald Campus to St. Emmanuel site - Google map

3.2 CONTROLLED DRAINAGE WITH SUB-IRRIGATION TECHNOLOGY

In Quebec, there are over 735,000 ha of cropland with subsurface drainage (Gollamudi, 2006). ICID (2011) recorded a total of over 2.5 million ha of agricultural land in Ontario and Quebec with subsurface drainage. Generally, the topography in this region is favourable for the installation of subsurface drainage and a large proportion of drained fields are used for field crop production.

These subsurface tile drains are open all year round and the lack of control could lead to potential nutrient run-off (Nyvall, 1998). However, the CDSI technology has the potential to increase crop yields and provide environmental benefits (Doering et al, 1999). The yield changes and environmental effects are however affected by the biophysical characteristics of the region.

This economic analysis is built upon the experimental site in St. Emmanuelle and is based on farm-scale corn yield data from CDSI and FD treatments. The subsurface irrigation component was used only during periods when precipitation was low, therefore the pumps were not turned on each year for the duration of the project. The standard life expectancy of the plastic perforated pipe used in subsurface drainage is about 50 years (Crabbe et al, 2012). Some of the experimental fields in this study have been tile drained with plastic pipes for 26 years.

During the growing season, in order to obtain desired water table depths water was pumped from a deep well to water control tanks. The basic components of the control system included: a ball valve to change from FD to CDSI, water table control chamber, float valve to control water supply, and overflow to permit drainage during controlled drainage with sub-irrigation (Tait et al, 1995).

In the experimental field, the drainage systems consisted of plastic 250 mm diameter PVC pipes with 2 mm holes along their whole length, approximately 5 cm apart and wrapped in geotextile to prevent clogging with fine soil particles. The tiles were installed at approximately 1 m depth in the soil with a spacing of 15m. At the discharge end of each lateral, a 5m length of non-perforated pipe was attached to allow for a transition into individual 51mm PVC mains.

Water level control in the structures was achieved via water stop-logs, so that water levels in the field that exceed the height of the stop-logs will overflow into the tile outlet that drains into the stream. Tile drainage management can be flexible. In this study, tile drainage is managed throughout the planting season; water table depth was monitored every 7-10 days using observation pipes installed in each plot. Figure 4 below is a diagrammatic representation of the field layout in St. Emmanuelle, showing the tile drain pipes and gas sampling chambers.

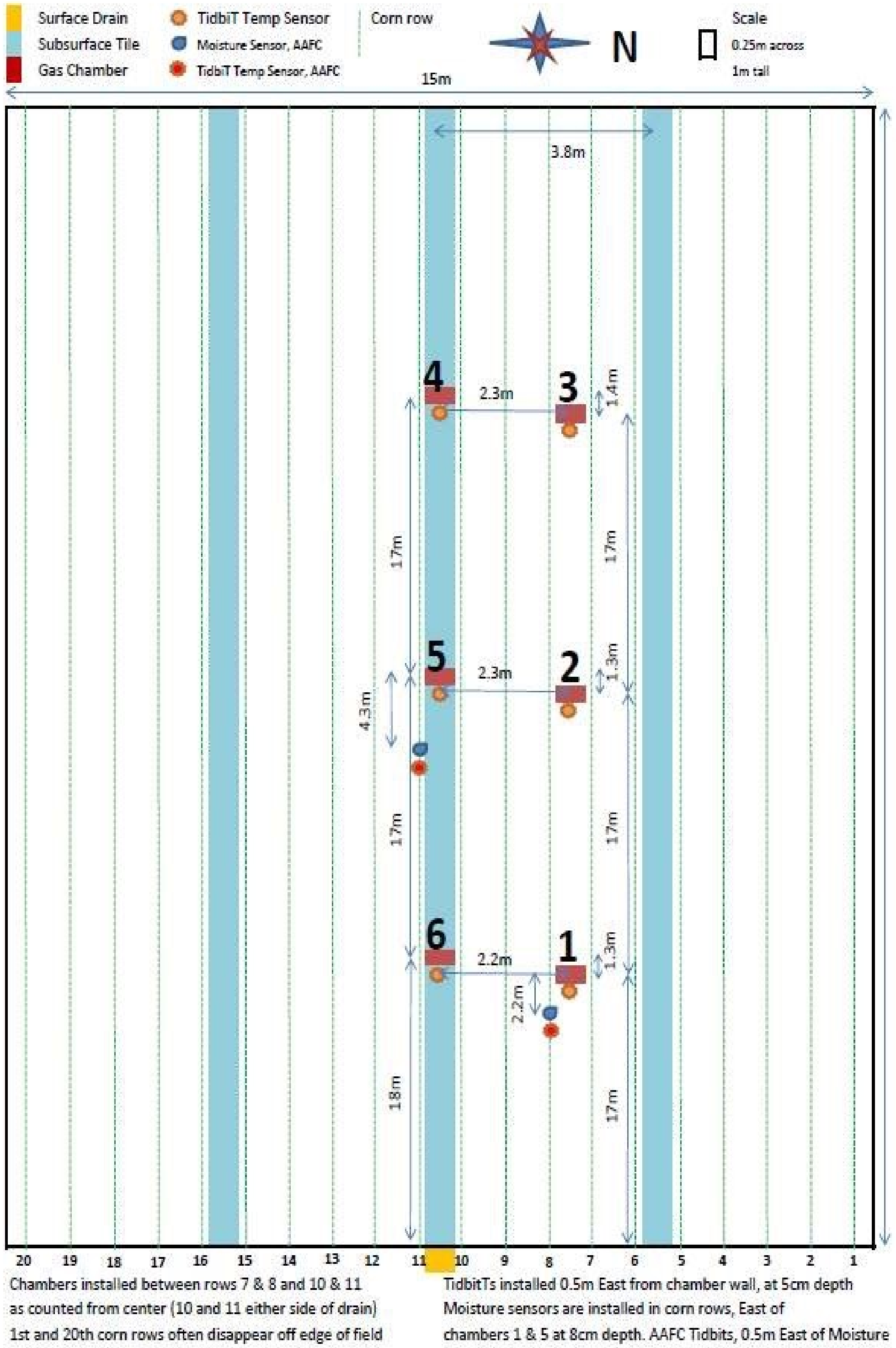

Figure 4 - Sampling Chamber layout diagram for a plot (Singh, 2009)

3.2.1 CROP PRODUCTION

Yield data were obtained from the AGGP representative working on the field (4.2ha). The crop production pattern was corn-soybean rotation in previous years.

CORN PRODUCTION

The growing season was 171 days (May 2nd to October 20th). Thes crop yield data was 9.56t/ha under FD treatment and 9.68t/ha under CDSI and Crop Heat Units (CHU) were 2900 and 2800 respectively which indicates a 1.3% yield increase under the CDSI treatment. Inorganic fertilizer was incorporated into the soil. The rate of application was: 10kg of N/ha, 20kg of P/ha and 8kg of K/ha in fall preceding the growing season and the tillage practice was performed at the same time. At seeding time; 43.71kg of N/ha, 80.70kg of P/ha, 50.44kg of K/ha, 5.38kg of Mg/ha, 5.04 kg of Ca/ha and 7.73 kg of (Boron) B/ha were incorporated into the soil and on May 29th, 115kg of N/ha was also incorporated, based on soil requirements. Also, 4.3l/acre of Marksman Atrazine and 1.5l/ac of dual II Magnum Herbicides were applied. Precipitation was frequent except for a few days in July but was sufficient for crop development.

Annual precipitation was 482mm, with very hot days and unbalanced precipitation in June – July, which are critical months in the life cycle of the crop. As a result, water table management treatments were used. Although, the lack of rainfall did not seem to do much harm to crop production. In addition, 220ml/ha of Converge Flexx and 1.5l/ha of Aatrex herbicides were incorporated at seeding. Table

2 below shows a historical presentation of yield data from the site. This data was used to forecast future yield data for the on-farm analysis.

Table 2 Comparisons of FD and CDSI on corn yields in St. Emmanuelle

Year	Ppt (mm)	Yield FD t/ha	Yield CDSI t/ha	Higher yield	Diff in yields (%)	Reference
1993	482.4	8.0	8.2	CDSI	2.5%	Zhou et al, 2000
1994	443.9	8.9	9.4	CDSI	5.6	
1995	479.3	11.1	11.4	CDSI	2.8	Mejia et al, 2000
1996	500.9	6.8	7.3	CDSI	6.9	
1998	618.2	8.8	6.6	FD	25.0	Madramootoo et al, 2001
1999	482.0	9.7	9.5	FD	1.7	
2001	365.4	6.9	9.4	CDSI	36.2	Stampfli & Madramootoo, 2006
2002	476.2	7.6	10.1	CDSI	32.9	
2008	431.9	12.5	12.3	FD	2.2	Singh, 2013
2009	461.7	11.3	10.4	FD	8.0	
2014	482	9.56	9.68	CDSI	1.3	This Study

Although table 2 above shows that there is a little difference between the yields of the two systems, it is important to test if there is a statistically significant difference in the mean and variance of the CDSI and FD yields. To accomplish this, the F – Test and t – test were used.

Table 3 Statistical test of difference (variance and mean) between CDSI and FD

A	Test of Homogeneity of variance
Hypothesis	$H_0: \sigma^2_D = \sigma^2_{WT}$
	$H_1: \sigma^2_D =/= \sigma^2_{WT}$
Observed value	$F_{obs} = 3.45/2.76 = 1.25$
Critical value	$F_{0.975}$ (10,10) = 3.53
Decision rule	If observed value < critical value, accept H_0
Conclusion	$\frac{\textit{Pooled } S2: (11-1)*3.45+(11-1)*2.76}{11+11+2}$ **=3.105** **Accept H_0**
Standard deviation	$S^2_D = 3.45$
	$S^2_{WT} = 9.19$
Mean	$X_D = 9.196$
	$X_{WT} = 9.48$
B	**Test of difference of mean**
Hypothesis	$H_0 : \mu_D = \mu_{WT}$
	$H_1: \mu_D =/= \mu_{WT}$
Observed value	$\frac{9.48-9.18}{\sqrt{3.105*\left(\frac{1}{11}+\frac{1}{11}\right)}} = \frac{0.3}{0.75} = 0.4$
Critical value	$t_{0.975}$ (11+11-2) = $t_{0.975}$ (20) = 2.09
Decision rule	If observed value < critical value, accept H_0
Conclusion	**Accept H_0**

Source: (René Roy 2016, Montreal, Canada: McGill University)

Table 3 part a, shows the test of homogeneity of variance, the Null hypothesis (H_0) states that FD (σ_D) = CDSI (σ_{wt}), the observed value is 1.25, while the critical value is 3.53. The decision rule states that if the observed value is less than the critical value then we fail to reject the null hypothesis that the variance of FD = CDSI. Part b, shows a test of difference of mean and the conclusion based on the statistical test was that we fail to reject the Null hypothesis that the mean of FD = CDSI. Thus, based on the above tests there is no significant difference statistically between FD and CDSI.

3.2.2 GREENHOUSE GAS EMISSIONS

The AGGP gas sampling protocol, calculations and modeling of errors in trace gas samples were based on the Hutchinson and Livingston model (Hurst, 2012). The gas chamber frames used were 1⁄4 inch Plexiglas with dimensions of 55.6cm x 55.6cm x 14.0cm, with 10cm buried in the soil and 4 cm above the soil surface to prevent gas diffusing laterally into the confined area because gas flux estimates can be unreliable if the insertion depth allows lateral diffusion to impact the chamber headspace concentration (Livingston et al, 2006).

The chamber covers are made of Plexiglas, with dimensions of 56.4cm x 56.4cm x 13.0cm and a closed-cell foam seal, to make an airtight seal. The top and side surfaces of the chamber covers are covered in a reflective aluminum-coated bubble wrap to reduce the effects of solar warming during deployment, which can lead to absorption or dissolution of dissolved gasses and influence microbial activity (Baker et al, 2003).

Each chamber cover had 2 holes drilled into the top. The 1⁄4inch hole was to allow placement of a septum for withdrawal of gas samples, while the 5/8inch hole was for the placement of a vent tube. The vent tube was to equalize the pressure within the chamber caused by air removal during sampling and increases in air volume due to the solar heating of the chamber during deployment. To ensure the deployed chamber covers joined with the chamber frames to form a "perfect seal", a 5kg bag of sand was placed in the center of the chamber cover immediately upon installation. The chamber frames were installed a week after seeding and removed just before harvest in the fall.

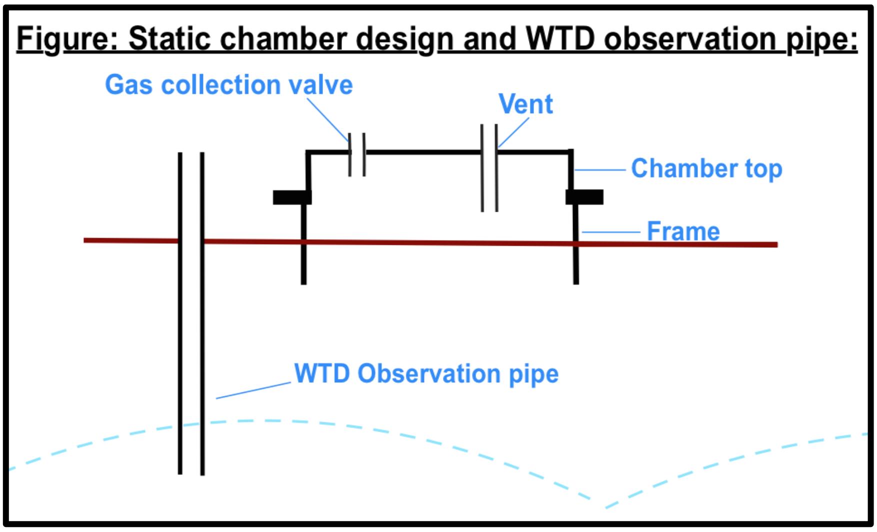

Figure 5 Chamber design (Hurst, 2012)

Gas samples were collected weekly throughout the growing season using a 30ml plastic syringe, which was placed in the septum of the chamber cover to withdraw gas. 22-25ml of gas were withdrawn for each sample, and injected into 12ml of evacuated Exetainers, sealed with two septa to avoid sample leakages. Gas data were analyzed using gas chromatography in a Bruker 450 GC at the McGill University Department of Natural Resource Sciences laboratory.

Figure 6 below shows a pictorial view of the Gas Sampling Chamber on the plots at St. Emmanuelle. Approximately 12 chambers were placed on the field in St. Emmanuelle.

Figure 6 GHGE Sampling Chambers (Hurst, 2012)

In 2013, grain corn was produced under field drainage and inorganic fertilizer was applied. Estimated GHG emissions were 1042Kg CO_2e. Tillage practices were performed in October of the previous year, followed by a harrow with teeth in the spring, right before seeding. Fertilizer and herbicides were applied at seeding. Although weak sinks, grain corn producing soils are methane sinks under various water treatments and fertilizer applications.

In 2014, annual precipitation (growing season) was 482mm, which was lower than the 30 year regional weighted average precipitation of 526mm, with warmer and drier periods during the critical crop growth stage. Thus, controlled drainage with sub-irrigation technology was used. Gas emissions were greater in the CDSI treatment for N_2O and CO_2 by about 50% and 17.4% respectively. There was more CH_4 reduction under the FD technology by 60% approximately. Overall, CDSI gas emissions were 1510kg CO_2e while FD emissions were 640kg CO_2e.

3.3 METHODOLOGY

This section discusses the methods used in carrying out the Benefit Cost Analysis (BCA) in this study. The analysis evaluates the impact of adopting water table management from both an on-farm/farmer and off-farm/societal perspectives. Several authors (Gittenger, 1982; Hanley and Spash, 1993; Boardman et al, 2011) have recommended the use of BCA as an economic and financial tool to estimate the impact of adopting a “new” technology on the farmer and from a government or societal perspective. The first sub-section below reviews the methodology for estimating on-farm impacts.

3.3.1 NET PRESENT VALUE ANALYSIS

To estimate the Net Present Value (NPV) for installing alternate technology, a farm budget analysis is employed in order to calculate the benefits and costs of each treatment and evaluate net benefits from changing to an alternative technology or production process. Farm inputs and outputs are measured in monetary terms to provide a common denominator for the valuation of impacts.

When carrying out a farm budget analysis, it is important to have good knowledge of opportunity costs, marginal concepts and risks. It was assumed that the farmer's objective was profit maximization (See Boehlje and Eidman, 1984 for other farm objectives, resource use pattern and constraints).

The NPV analysis is undertaken by taking into account system costs, production costs and revenues. The Excel random number generator with defined value distributions was used to forecast some production costs and crop price data over the useful life of the CDSI and FD systems.

Estimating Crop Production Costs

This sub-section describes how farm input prices of fixed costs and variables costs are derived and some factors to note when including these farm inputs in the budget. This information is essential to the farm manager. Corn Prices are derived from averages from CRAAQs and Statistics Canada and forecasted using Excel Random number generator with defined value distributions.

Seeds

Using certified Roundup Ready seed technology (RR), seeding cost in the region is approximately $118/80,000 kernels per hectare but varies depending on the cultivar. The price is an average of various cultivars provided by different retailers. Prices were derived from CRAAQ 2014.

Fertilizer, Limestone, and Pesticides

Prices were based on mineral fertilizers and were derived using Centre de reference en agriculture et agroalimentaire du Quebec (CRAAQ) and OMAFRA 2012 - 2014 grain budgets as guidelines and calculated to show the actual quantity used in the experimental field. The recommended quantity was determined after soil tests were conducted. Prices include the purchase of fertilizer in bulk with delivery and spreading. Limestone and pesticide prices were also included along with spraying costs for equipment and transportation.

Labour and cultivation operations

In the previous fall, some tillage practices were carried out; total labour for these operations on a per hectare basis were estimated to be 14.4hours on average for hired or family labour. Also included as labour costs were: maintenance and repair of tractors and machinery, salary of an operator, weeding, and transportation.

Land rent

CRAAQ (2015) notes that the rental price of land is the result of negotiation between the owner and the tenant. As well as other factors, such as supply and regional demand, the increase in the value of land, the indirect revenues associated with land ownership and the number of hectares should be considered. An actual market price for land rent was not included in the budget. Land rent was not included because CRAAQ budgets do not take into account of debt/equity structure for a farm in their budgets.

Some other factors included in the budget analysis are crop insurance and interest on short-term financing.

3.3.2 BENEFIT-COST ANALYSIS

It is important to carry out a BCA because sometimes agricultural projects that increase profitability may, in fact, decrease environmental sustainability. BCA is a valuable tool that can be used for evaluating environmental and biodiversity projects (Pearce et al, 2006).

Boardman et al (2011) defined Benefit Cost Analysis as "*a policy assessment* *method that quantifies in monetary terms the value of all consequences of a policy to all members of society*" (Boardman et al 2011, p. 2).

It can be shown as:

$$NSB = B - C$$

Where; NSB= Net social benefit, B= Net present value of Benefits and C= Net present value of Costs. Therefore, these scenarios exist, when NSB > 0 the project is beneficial and should be undertaken, and when NSB < 0 the project shouldn't be undertaken; although, this is not always the case. An example is the construction of the bridge from Prince Edward Island (Townley, 1998). When NSB = 0 then it is usually left to policy makers to decide or other aspects of the project are considered including an adjustment in the discount rates. Also, there are some disagreements regarding the possibility or impossibility of intra- and intergenerational utility trade-offs as well as how best to assign a monetary value or price of some impacts on the study. Some of these are discussed when reviewing discounting.

Various literature (Gittenger, 1982; Hanley and Spash, 1993; Townley, 1998; Boardman et al, 2011) have different approaches or steps to follow when carrying out a proper benefit cost analysis. However, there is a consensus on the fact that the analyst has to identify the alternative(s), decide which costs and benefits should be considered, identify and quantify the impacts and assign monetary values to them, discount the value to reveal present costs and benefits and last to conduct a proper sensitivity analysis to test the model.

3.3.2.1 WHY USE BENEFIT COST ANALYSIS

The main objective of most projects, more specifically agricultural technology adoption is to provide farmers with benefits and costs associated with the technology to enable them to choose more rational and beneficial courses of action. Economists are often concerned with resource use efficiency, environmental sustainability and societal welfare improvement in general. Pearce et al (2006) outlined some reasons why BCA is a preferred evaluation tool: (i) BCA assumes that all projects should be seen as having substitutes and therefore takes into account, all the benefits and costs of achieving alternate projects; (ii) BCA emphasizes the importance of individual time preference rigorously through discounting; and (iii) using discounting helps analysts view future benefits and costs in present value terms (Boardman et al, 2011).

Although there are some opponents who argue that the above reasons are not sufficient to justify the use of BCA. There is however, a consensus that quite a number of these attributes are attractive as a tool for measuring project impacts, making BCA a recognized method for assessing projects.

3.3.3 DETERMINING, QUANTIFYING AND VALUING OF COSTS

Direct Costs to the farmer included farm inputs for production. These can be easily identified, including some of them such as labour and energy costs as mentioned above. Other direct costs included the cost of installation or cost of retrofitting an existing tile drainage system with a control structure and sub-irrigation system. These costs included: land preparation, cost of control structure, costs of pipe for control, cost of the pump, deep well installation costs operation and maintenance costs. Prices for production costs were derived from CRAAQ budgets, OMAFRA budgets and Statistics Canada while, prices for the installation of CDSI were gathered from several sources including: CRAAQ, contractors, literature and personal communication with the AGGP Team (Head – Chandra Madramootoo, 2015).

Direct Costs to Government included: subsidies, potential grants for irrigation investment, and costs of increased Greenhouse Gas Emissions where applicable. For example, the public would bear the cost of increased nitrate loading in watersheds because it causes pollution.

Indirect Costs to the farmer may include adapting to the irrigation system, monitoring soil moisture content, and monitoring precipitation data. On the other hand, indirect costs to the government are more difficult to identify and quantify and even more difficult to monetize. For instance, nitrogen leaching into water bodies causing nitrate contaminants in drinking water can cause health problems (Gelberg et al, 1999). Increased GHG Emissions are also a major concern of the government as they have a mandate to reduce GHG emissions and are liable to pay the UNFCCC for increased emissions.

In the analysis section of the thesis, costs (direct and indirect) are typically broken down into sections of variable and fixed costs when computing production costs and investment costs when calculating system costs for the BCA. Variable costs differ from fixed costs in that they are under the control of the farmer in the short run and tend to rise as production increases; such as fertilizer costs, labour, seeds and energy costs. Fixed costs are costs that usually occur at the beginning of a farm enterprise and last over a long period of time or are a one-time lump-sum investment such as land, investment costs of the irrigation system and interest on term loans (Boehlje and Eidman, 1984). Fixed costs are not linked to production levels.

Production costs were calculated on a per acre basis. The experimental field area was 4.2 hectares, which is equivalent to 10 acres. Variable costs were computed for the 2014 crop production year because yield data and GHG Emissions data were recorded for both water management systems for the same year. However, yields for 11 years for both irrigation systems were used to project yields into the future.

3.3.4 DETERMINING, QUANTIFYING AND VALUING BENEFITS

Direct benefits to the farmer are the potential for increased crop yields as a result of increased uniformity in the field's productivity over the useful life of the technology. This could lead to increased farm income to the farmer through increased revenue when crop market prices are constant or increase and production costs or input prices remaining constant or increase at a slower rate than output prices.

Indirect benefits could include the potential to grow more high valued crop varieties in the area, increased crop quality which could result in better crop sales although, this has been recorded mostly for vegetable crops. In this thesis, only direct benefits were evaluated. Indirect benefits would include reduced nitrate loading in drainage water.

The analysis for this thesis focused on direct benefits to the farmer from potential increases in crop output. There is a need to evaluate the off-farm impacts from installing CDSI, however this thesis only includes GHG emissions from the soil. It does not include other off-farm impacts such as nitrate in the water.

Monetizing benefits or assigning market values to benefits, the yield data were collected from the experimental field per hectare and then converted to a per acre value (although Canada uses metric measurements, several farm studies in North America use the imperial/standard measurements). The values were then multiplied using 2014's corn prices obtained from FADQ to derive revenue from each water management treatment. The experimental field data were similar to actual yield statistics from the region.

3.3.5 DISCOUNTING

A major component of BCA is determining what discount rate to apply to costs and benefits, since BCA typically compares projects over time. Environmental economists cite intra- and intergenerational transfers and equity as a justification for discounting. Discounting takes into account the time value of money. Several studies (Harrod, 1948; Hanley and Spash, 1993) propose that discounting has various utilitarian attributes and believe that future generations can be harmed by current practices.

On the other hand, environmentalists argue that discounting represents the value individuals place on goods. In recent times, there has been somewhat of a consensus on the need for discounting, however, what remains a source of continuous debate is what rate should be assigned for discounting.

Boardman et al (2011) suggest two ways of analyzing benefits and costs for the short term (a year) and long-term (over a year) projects.

1. Present Value Analysis: $PV = \frac{Y}{1+i}$

   And Present Value over years: $PV = \sum_{t=0}^{n} \frac{Y}{(1+i)^t}$

Where PV = present value, Y = present value of amount received in time t, i = prevailing discount rate and t = time frame

2. Net Present Value Analysis: $NPV = PV(B) - PV\ (C)$

And Net Present Value of a project $NPV = \sum_{t=0}^{n} \frac{B_t}{(1+i)^t} - \sum_{t=0}^{n} \frac{C_t}{(1+i)^t}$

Where NPV = Net present value, $PV(B) = \sum_{t=0}^{n} \frac{B_t}{(1+i)^t}$ (Implying a summation of benefits accrued over time "n") likewise PV(C).

Also, Pearce et al, 2006 propose a simple method for assigning discount rates.

Discount Formula: $w_t = \frac{1}{(1+i)^t}$

Where; W_t = discount factor, i = discount rate and t =time

When W_t <1, it implies discounting (Pearce et al 2006).

3.3.5.1 CHOOSING A DISCOUNT RATE

The choice of a discount rate is crucial as it affects the outcome of the net present value. Also, it shows an individual's rate of time preference, as most individuals treat present consumption being more important than future consumption.

According to Hanley and Spash (1993) the social discount rate is typically less than the individual discount rate for several reasons including:

i. Society's collective savings rate will be greater than an individual savings decision

ii. When evaluating environmental costs and benefits, individuals as members of a society have different inter-temporal preference compared to the same individual as a sole consumer, and

iii. Individuals with finite life expectancies are likely to value current private consumption decisions differently from a society with expectancy of life in perpetuity (Hanley and Spash, 1993).

The discount rate, number of years the project impacts the farmer, and environment are essential when calculating the NPV and BCA. The purpose of discounting is valuing future benefits or costs at the present value of the project, this also deals with time preference and opportunity cost of capital (Savva et al, 2002). Lower discount rates imply a higher net present value and higher discount rates imply a lower present value.

3.3.5.2 PRIVATE DISCOUNT RATE

Boehlje and Eidman (1984) recommend the use of the weighted average cost of capital to derive the discount rate.

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

Where d: weighted average cost of capital, K_e: after-tax rate of return on long-term equity capital, W_e; proportion of equity capital, K_d: long-term interest rate on debt for each farm, t: marginal tax rate and W_d: long-term proportion of debt. This discount rate is typically preferred for the private (on-farm) benefit cost analysis. It is usually higher than the social discount rate and is essentially a combination of the cost of equity and after-tax cost of debt.

3.3.5.3 SOCIAL DISCOUNT RATE

The discount rate has to be chosen carefully because it determines what value is placed on present day benefits and costs. The discount rate affects the NPV and can present results that may dissuade or encourage the adoption of a technology. The level of patience and attitude towards projects that improve environmental quality can be revealed in the discount rate.

$$\frac{1}{(1+i)^t} = DF$$

Where; i; discount rate, t; number of years and DF; discount factor. The Treasury Board Secretariat (2007) recommended a Social Discount rate (SDR) of 8%; however, Boardman et al (2011) recommend a SDR of 3.5% stating that if a project is less than 50 years 8% rate is too high and a project exceeding 50 years should employ a time declining discount rate. Burgess (1981) on the other hand, recommends a social discount rate ranging from 6.1 to 8.2%. Sassone and Schaffer (1978) suggests that the SDR be based on social opportunity cost of capital (SOCC) i.e. opportunity cost of money should be reflected in the investment's costs and not in the discount rate. Thus, the choice of discount rate may be low, but the opportunity cost of resources is embedded in the project's costs as the social opportunity cost of capital (SOCC). Then the SOCC is calculated as a factor that is subtracted from the project's present value of benefits calculated with a low discount rate. Boardman et al (2011) suggest that a SDR derived from market-based interest rates is not advisable. Other ways of choosing the SDR are:

- ✓ Using the Shadow Price of Capital

This technique is used to estimate benefits when normal economic analysis is ineffective; e.g., how much individuals would be willing to pay annually to improve the environment.

- ✓ Using the Optimal Growth Rate Approach to discounting

Spiro (2010) argues that the appropriate discount rate is not fixed, and varies with financial market conditions. His paper suggests a real discount rate of about 5% which is appropriate for a provincial government benefit-cost analysis of investment projects. However, when the opportunity costs of capital declines, the implied discount rate in that period will decrease. He mentioned that the SDR could change over time but it is important to experiment with sensitivity analysis that reviews the SDR for a range of possible values. In this thesis, the irrigation technology is discounted over 20 years following Crabbe et al (2012) study. Hanley and Spash (1993) concluded that no unique rates exist due to market imperfections and distortions; hence the social discount rate should be decided by the government.

3.3.6 SENSITIVITY ANALYSIS

A proper sensitivity analysis is crucial to test the robustness of the results by accounting for production disparities with the project such as price instability. A sensitivity analysis is conducted to assess profitability in a scenario of optimal planting and harvesting under experimental condition.

Sensitivity analysis is also used to account for agronomic challenges (e.g. delay in project implementation) identified under the project reports and assumptions on yield calculations. The sample yields do not account for best-case scenarios for the technology, thus the sensitivity analysis would endeavor to accommodate potential increases using the scientific literature as a reference point and a decrease in yields to evaluate the change in net present value. The sensitivity analysis is used to estimate the impact on net present value from changes in discount rates and variable costs and recommendations of what technology to adopt are made after the analysis is completed.

3.3.7 CRITICISMS OF USING BCA

Criticisms of BCA are based mainly on its theoretical or economic foundations. The welfare theory upon which BCA is based comes from the concept of a potential Pareto improvement. The difference between a potential Pareto improvement and an actual Pareto improvement is that gainers from a change in policy do not have to compensate the losers of the policy change. For a potential Pareto improvement to become an actual Pareto improvement compensation would have to be paid. A major disagreement that arises from this concept is the reversal paradox (see Scitovszky, 1941 for a demonstration). The reversal paradox can be taken into account by imposing Scitovszky's double-criterion (Gowdy, 2004).

Another problem is with Willingness to Pay (WTP) as a measure of aggregate benefits because attempts to aggregate social welfare functions may not hold as aggregate individuals' welfare varies. As a result, there may be no consensus on the social welfare function. The idea of treating the marginal utility of gainers and losers equally is flawed, since taking into account that modern day economics rejects cardinality. Therefore, positive net benefits may not bring about optimal results or solutions. (Boardman et al, 2011)

In reality, BCA recommends projects that report an increase in net benefits but does not tackle the income distribution question (Hanley and Spash, 1993; Gowdy, 2004). When employing BCA in environmental projects, ecosystem complexity makes economy-ecosystem interactions difficult. Understanding environmental impacts is complex, especially when the issue of inadequate information or inefficient communication of information regarding impacts of a lost (or gain) in environmental good or service arises. This could cause individuals to make choices that may risk social objectives. Also, the problems of market inefficiencies and price inaccuracies can make it difficult to adequately measure environmental impacts although this can be handled by using shadow prices or values.

Taking the reviews above into consideration, it is important to note that the BCA framework distinguishes between different aspects of a project, this allows attention to be directed to specific areas of a project; such as components of benefits, costs, discount period and discount rate, and details the methods by which each aspect is addressed. Consequently, BCA provides useful inputs into environmental management assessments, but there is certainly room for improvement. The analyst and end-users should bear this in mind.

3.3.8 FORECASTING

There are several required when determining forecasts of crop yields, crop prices and crop production costs including historical data or trends, weather conditions, increased production of biofuels, foreign exchange fluctuations and changes in production processes influence forecasts (Allen, 1994; Just and Weninger, 1999). Production forecasts are typically based on the quantifiable features of growing crops, while price forecasts are largely produced by conventional econometric methods.

Although there is no consensus of non-normality for crop yield distributions, several studies (e.g. Moss et al, 1993; Koundouri and Kourogenis, 2011) have come to the conclusion that crop yields and prices are non-normally distributed. Most proponents have observed that crop yields and prices exhibit skewness and kurtosis.

When predicting revenue i.e. yields and price forecasts, Tew and Reid (1998) observed that price-yield correlation is a major influence in determining the skewness of revenue. Hence, normality for revenue may not be rejected even if the price and/or yield distributions are significantly skewed. However, depending on the coefficient of variation of the yield and price, normality may not be rejected for revenue even with a weak correlation between price and yield. Nevertheless, the assumption of non-normal distributions of revenue in risk analysis appears to be much less serious when prices are allowed to be stochastic or exhibit a uniform distribution than when a constant price assumption is imposed.

3.3.8.1 PROJECTING YIELDS AND PRICES

The Random Number Generation analysis tool fills a range with independent random numbers that are drawn from one of several distributions. One can characterize the subjects in a population with a probability distribution. For example, one can use a uniform distribution to characterize the price predictions.

UNIFORM DISTRIBUTION

When you ask for a random set of say 100 numbers between 1 and 10, you are looking for a sample from a uniform distribution, where $\alpha = 1$ and $\beta = 10$ according to the following definition.

The uniform distribution has a probability density function (pdf)

$$f(x) = \left(\frac{1}{\beta - \alpha}\right) \alpha \leq x \leq \beta$$

0, otherwise

Where α and β are lower and higher bounds from the historical data i.e. with $\alpha < \beta$.

NORMAL DISTRIBUTION

The probability density function of the normal distribution is defined as:

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

Here, the constant *e* = 2.7183 and is the constant π = 3.1415… which are built-in excel Functions.

The normal distribution is determined specifically by the parameters μ and σ. The mean μ is the mean derived from the historical crop yield or price data and σ is the standard deviation. *N* (μ, σ) represents a normal distribution with mean μ and standard deviation σ. This has been built into Excel.

CHAPTER 4

RESULTS AND DISCUSSION

4.1. ON-FARM COST (TECHNOLOGY COSTS AND PRODUCTION COSTS)

Identifies and estimates the on-farm costs and revenue of the two irrigation systems. The next section includes the forecasts of revenue, costs and the NPV from the farmers' perspective.

4.1.1 COST OF INSTALLING CONTROLLED DRAINAGE WITH SUB-IRRIGATION VERSUS FIELD DRAINAGE

The costs of controlled drainage with sub-irrigation technology were calculated on average field conditions on an experimental site in St. Emmanuelle, Quebec. The system costs are broken down into Fixed Costs and Variable Costs.

FIXED COSTS

The components of the system are mainly durable goods; thus the costs are annualized into depreciation and interest components. The cost of the CDSI system included depreciation because its expected useful life is 20 years. It also included interest costs because the calculations are based on an assumption that the money is borrowed or that the use of the owner's equity capital comes at an opportunity cost (Crabbe et al, 2012). The interest rate used was 2.19%, and it was assumed that the farmer would have saved the money in a Guaranteed Investment Certificate (GIC) over 10 years which is the loan period for the technology.

VARIABLE COSTS

These costs include the cost of operating the system, repairs and maintenance, fuel, and labour. Repairs and maintenance were estimated as a fixed percentage of the initial investment for components such as tubing, control structure and pumps (Evans et al, 1996). The annual depreciation on the control structure is 5% per year with an expected life of 20 years. The annual depreciation on tubing is 2% with an expected life of 50 years. The annual depreciation on the Deep well is 2% with an expected life of 30 years, and annual depreciation of 5% was assumed for the pump with an expected life of 20years (Crabbe et al, 2012). The Straight-Line Depreciation method was used for this calculation. Table 4 below shows a breakdown of these costs.

Table 4: Fixed and Variable Costs for installing CDSI

Fixed Costs		**FD (CAD$)**	**CDSI (CAD$)**
Tubing		1,046.71	1,046.71
Drainage Land Preparation		36.45	36.45
Control Structure		0	87.1
Water Supply			
Deep Well		0	113.7
Pump		0	402.14
Depreciation		20.93	46.92
Interest on term loans		103.93	162.27
Costs per ac	**Total**	**1,208.02**	**1,895.29**
Variable Costs			
Pipes	0.25% of investment	2.6	2.6
Control structure	2% of annual Amortized cost	0	0.01
Deep well	None assumed	0	0
Pump	1% of Fixed Cost	0	4.1
	Total	2.6	6.7

This analysis was calculated with 2012 material costs because the project was initiated in that year. A more detailed description of the system calculations is presented in the appendix below. Two systems (Field Drainage and Controlled drainage with sub-irrigation) were considered for comparison in this study.

One control structure (CAD $860.30) is needed, on average, for an area of 4 hectares (~10acres). In addition, the pump (CAD $4,021.40) is for a 1horsepower pump, used to supply water to about 4 hectares for corn production. The Deep well (CAD $5,615.35) in this study, on average, can be used for about 20 hectares of Land and calculations took this into consideration.

Table 5 below shows the investment costs and annual costs of FD and CDSI and the different between CDSI and FD. That is, to install CDSI on an existing FD system would cost CAD$607.97 per acre. The experimental field had existing tile drains and therefore the capital costs for installing CDSI are the costs for the control structure, installation of a deep well and pump. This study analyzed the costs of installing field drainage (FD) as well because statistics from the region show that farmers have the potential to install FD.

Table 5 Economic Comparison showing costs for the different water management systems

Costs per acre	Status Quo (a) (CAD$)	Alternate Scenario (b) (CAD$)	Difference between (b) and (a)
	FD	CDSI	**CDSI – FD**
Investment costs	1,083.16	1,691.13	607.97
Annual costs	20.93	47.92	26.99

4.1.2 PRODUCTION COSTS

Farm inputs are divided into variable costs and fixed costs. Variable costs are typically incurred annually; they include seeds, insecticide, fertilizer, lime, herbicides, custom work (for fertilizer and other agrichemical application), drying, crop insurance, storage, labour, repairs and maintenance costs. Variable costs for Corn were CAD $529.84 per acre.

Fixed Costs include depreciation, land rent, building rent and maintenance, interest on loan, which is different from short-term or operating interest rate and depreciation. Fixed costs were CAD $41.50 per acre, therefore the total cost of producing corn per annum was CAD $571.34 per acre on the experimental field.

Experimental field data were used in combination with CRAAQ data and FADQ data for the farm budget. The budget costs were the same for corn under different water management systems because the increase in labour as a result of the technology was accounted for in the annual cost calculation for the systems in the previous section. The variable costs were discussed in detail in the preceding chapter and more details on the calculations can be found in the appendix.

Table 6 Production Costs Per Acre for Corn

Farm Input per acre	Quantity	Price (CAD $)
Seed	80,000/ha – RR	118.62
Fertilizer	NPK (200:50:100)	170.04
Fixed Costs		41.50
Production Costs	Other farm inputs	241.18
	Total Costs	571.34

*RR- Roundup Ready Seeds, NPK – Nitrogen, Phosphorus, and Potassium.

REVENUE

Crop yields were collected for both treatments (CDSI and FD) and then scaled up to a hectare and then multiplied by 2014 corn prices obtained from CRAAQ.

Table 7 Yield Data for FD and CDSI for Corn

Yields per acre (2014)	Quantity (FD) t/ac	Price (CAD $)	Quantity (CDSI) t/ac	Price (CAD $)
Yields	3.87	197.05	3.92	197.05
Total		**762.58**		**772.44**

The CDSI had a yield advantage of about 1.3% and a revenue increase of CAD $9.86 per acre. The average corn yields for this region in 2014 is 9.1t/ha (~3.69t/ac). The

CDSI has a 6.23% increase over the provincial yield average hence, a potential revenue advantage of CAD $42.55 per ac.

4.2 NET PRESENT VALUE (NPV) ANALYSIS

The net present value analysis is computed to determine the present value of Controlled Tile Drainage with Sub-irrigation and Field Drainage.

The costs of the systems were computed for the duration of useful life of the systems. The interest rate for the technology was computed to be 4.75% for 10 years at an equity contribution of 25%. While, the useful life of the system was estimated for 20 years, thus the costs for the first 10 years include; annuity payment, opportunity cost of capital for the proportion of investment costs the farmer bears, depreciation, and variable costs. For the subsequent 10 years, only variable costs for operation and maintenance are considered.

Production costs for the first 10 years of the project were obtained using AAFC Farm input price indexes 2015-2024 and computed to account for percentage increases assuming the project year as the base year. For the subsequent 10 years (2024-2034), production costs were obtained using the random number generator in Excel given historical data and distributions to project values.

Yield data for 20 years (2015 – 2034) were derived by employing the random number generator (Excel) to predict into the future based on historical data (1993 – 2014) and assumed distributions from the farm site. Crop Prices for 10 years (2015 – 2024) were obtained from the “Medium Term Outlook” (Statistics Canada, 2015) and for the next 10 years (2025 – 2034) were derived using historical data (1993-2014) from FADQ, 2014 to predict prices into the future. The predicted values generated by Excel for the NPV are presented in the appendix.

The Private discount rate was derived using the weighted average cost of capital described in Chapter 3. Return on equity (ROE) is 7.93% (Statistics Canada, 2014) although 2013 ROE of 10.5% was used because it was more representative of the historical ROE and resulted in a higher discount rate. Three different Debt/Equity ratios were assumed 75:25, 50:50 and 25:75 to reflect younger farmers, middle age and experienced farmers or farmers who have been farming for a longer period (Statistics Canada, 2014). Return on long-term debt was assumed to be 2.95% (Bank of Canada, 2014) and the marginal tax rate in Quebec at 20% (FCC, 2014). The discount rates obtained were 3.75% for young farm operators, 6.43% for mid- farm operators and 8.47% for experienced farmers.

Net cash flow (NCF) was obtained by calculating the difference between the present value of benefits (PV) B and the present value of costs (PV) C in order to derive the Net Present Value (NPV) and Internal Rate of Return (IRR). The table below (Table 8a – c) shows the NPV obtained using different discount rates.

4.2.1 FORECASTS

Several studies using time series analysis to project agricultural prices and yields have proposed that forecasted crop yields and crop prices are non-normally distributed. There seems to be a consensus that crop yields are negatively skewed, while crop prices are sporadic or exhibit lognormal distributions. However, there is not yet a consensus on the distribution of projected production costs. Hence, for this study, it was assumed that four forecast scenarios for Crop prices, Crop yield, and cost of production were assumed in an attempt to assess the effect these values would have on NPV analysis.

OPTION A: In this scenario, it was assumed that the forecasted values for all variables were normally distributed.

OPTION B: In this scenario, it was assumed that the predicted values for all variables were uniformly distributed.

OPTION C: In this scenario, it was assumed that the projected values for crop prices were uniformly distributed while yields and production costs are distributed normally.

OPTION D: In this scenario, it was assumed that the projected values for crop prices were normally distributed while yields and production costs are distributed uniformly.

As shown in Tables 8 “a” through “c” below, the results of the NPV analysis are consistent for Options A to D with different discount rates. The results revealed that over the life of the technology, Field Drainage (FD) has a higher NPV than Controlled drainage with sub-irrigation (CDSI). Consequently, from a farmer’s financial perspective, based on the above results from all scenarios a farmer may not be willing to implement CDSI over FD based on the analysis presented.

The NPV analyzed different project scenarios; scenario 1, if the farmer takes a loan to install the technology “Farmer taking loan” and if the farmer uses farm capital “Farmer using own capital” (Table 8a, 8b, and 8c). It was observed that although the sum of technology costs was higher under the loan scenario than the no-loan scenario, the NPV was higher under the loan case. The lump sum capital costs are at the beginning of the period and more weight is assigned to the present than future values. Also observed was as the discount rate increased the profits decreased.

Table 8a NPV Analysis Results (2014-2034)

	FARMER TAKING LOAN		FARMER USING OWN CAPITAL	
	CDSI (CAD$)	**FD (CAD$)**	**CDSI (CAD$)**	**FD (CAD$)**
OPTION A	713.12	1501.5	549.32	1396.5
OPTION B	-575.96	385.6	-739.76	280.7
OPTION C	126.20	863.0	-37.59	758.0
OPTION D	-65.84	270.6	-229.64	165.7

@3.75% discount rate

Table 8b NPV Analysis Results 2

	FARMER TAKING LOAN		FARMER USING OWN CAPITAL	
	CDSI (CAD$)	**FD (CAD$)**	**CDSI (CAD$)**	**FD (CAD$)**
OPTION A	296.6	1040.3	-1.8	849.2
OPTION B	-636.6	203.8	--934.9	12.7
OPTION C	-154.0	495.0	--452.3	303.9
OPTION D	-233.7	82.9	-532.0	-108.2

@6.43% discount rate

Table 8c NPV Analysis Results 3

	FARMER TAKING LOAN		FARMER USING OWN CAPITAL	
	CDSI (CAD$)	**FD (CAD$)**	**CDSI (CAD$)**	**FD (CAD$)**
OPTION A	82.2	791.3	-3002.6	544.9
OPTION B	-657.5	113.1	--1042.2	133.3
OPTION C	-292.1	304.7	--676.8	58.3
OPTION D	-318.3	-12.8	-708.1	-259.2

@8.47% discount rate

The Internal rate of return (IRR) can be viewed as the expected annual return on the investment in a project. The results reveal that in Options B, C, and D, a farmer investing in CDSI technology will suffer losses under the loan case and would lose in all options assuming that no loan was taken (Table 9 below). In Option A, under the FD technology "farmer taking loan", the farmer has a 20.51% IRR. This implies that the payback period for the FD technology in Quebec for grain corn production with inorganic fertilizer (assuming no crop failure or other adverse effects) will be in five years approximately.

Table 9 Internal Rates of Returns (IRR)

	FARMER TAKING LOAN		FARMER USING OWN CAPITAL	
	CDSI	**FD**	**CDSI**	**FD**
OPTION A	2.86%	20.51%	-0.01%	7.30%
OPTION B	-8.96%	5.93%	-7.59%	0.15%
OPTION C	-1.53%	7.38%	-2.70%	2.46%
OPTION D	-3.25%	1.62%	-3.97%	-1.11%

The Benefit Cost ratio indicates how much the farmer would get for every Canadian dollar spent. Thus, in option A assuming the farmer takes a loan, for every C$1 spent, the farm will gain 3 cents per acre for CDSI and 13 cents for FD (Table 10 below). While in option D loan scenario, for every C$1 spent the farmer loses 3 cents under CDSI and gains 1 cent under the FD treatment.

Table 10 Benefit Costs Ratio (BCR)

	FARMER TAKING LOAN		FARMER USING OWN CAPITAL	
	CDSI	**FD**	**CDSI**	**FD**
OPTION A	1.03	1.13	0.99	1.10
OPTION B	1.07	1.15	0.90	1.00
OPTION C	0.98	1.06	0.95	1.04
OPTION D	0.97	1.01	0.94	0.99

4.3 POTENTIAL OFF-FARM COSTS AND BENEFITS

This sub-section investigates the public benefit cost analysis for the two technologies. The off-farm benefit-cost analysis is computed to determine the social impact of the technology. There are several components that should be considered when conducting a detailed Public benefit-cost analysis and it could be viewed from different perspectives. This thesis evaluates off-farm costs and benefits from two perspectives.

First, the Crabbe et al (2012) study estimated total cropland area in the region, calculated the proportion of the land suitable for installation of controlled drainage based on its biophysical characteristics and the portion dedicated to grain corn and soybean production. This approach for this thesis would be somewhat redundant as the private BCA results presented above show that FD has the greater NPV.

The second approach, which was undertaken included the estimated GHG emissions from this project and monetize the impact to enable an economic valuation of the impact. GHG emissions are usually measured in its Carbon equivalent (CO_2e) in metric tonnes. In Quebec's Carbon trading market the minimum auction price has been set at CAD $11.39/MT and a potential annual increase of 5% plus inflation (Government of Quebec, 2014). The GHG emissions' price is used in this analysis because the Quebec Carbon market was established in 2012 and is still undergoing some amendments. The analysis followed the guideline specified by Quebec Government's Carbon market for calculating GHG emissions. The discount rates applied to the NPV analysis from the public perspective is the social discount rate suggested by Boardman et al (2011), Spiro (2010) and Treasury Board Canada (2007) and these are; 3.5%, 5%, and 8% respectively.

The loan scenario of the on-farm results was used to compute the public benefit cost analysis because the loan case of the on-farm results revealed more favorable results for all options for both technologies (CDSI and FD). Table 11a, 11b and 11c below shows the results given the different discount rates.

Table 11a NPV Analysis Off farm

	CDSI (C$)	FD (C$)
Option A	254.92	1,339.60
Option B	-1075.05	192.50
Option C	-347.44	691.30
Option D	-553.29	77.80

@3.50% social discount rate

Table 11b NPV Analysis Off farm results 2

	CDSI (C$)	FD (C$)
Option A	64.9	1,081.1
Option B	-1040.9	107.3
Option C	-452.3	488.5
Option D	-584.6	-10.2

@5.0% social discount rate

Table 11c NPV Analysis Off farm results 3

	CDSI (C$)	FD (C$)
Option A	-193.2	707.4
Option B	-972.8	-3.9
Option C	-583.4	208.2
Option D	-620.1	-128.6

@8.0% social discount rate

The monetary costs to society over 20 years at a 3.50% social discount rate (Option B) for installing CDSI on each acre is C$1,075.05. Table 11a above, reveals the project under FD at a 3.50% discount rate produces net returns of $1,339.6. This result would raise research questions of the impact for farmers with no drainage system and may lead to policy implications. Total farmland in Quebec is approximately 8.6 million acres, Statistics Canada (2011) and total farmland equipped with drainage system was about 1.9 million acres (ICID, 2011). Hence, there is potential for the installation of more drainage systems.

The GHG emissions data revealed a 135% increase in costs from installing CDSI because it led to a substantial increase in GHG emissions under CDSI compared to FD. The results showing high increases in atmospheric GHG emissions and is not consistent with the literature (See Verma et al, 2005). There is a need for research to further investigate CDSI on GHG emissions.

The BCR results show that there is a 12 cent gain under FD (Option A) for installing the technology. However, it is noteworthy to bear in mind that GHG emissions have several other impacts as mentioned in the literature of this thesis.

Generally, the results require more observations with different water management systems such as Controlled drainage without sub-irrigation, with inorganic and organic fertilizer scenarios as the literature reveals that these variables affect GHG emissions. Also, several studies (see literature review section) showed that CDSI and Controlled drainage technology reduced nitrate loading in watersheds. It would be interesting to measure the change in nitrate loading under the different water treatments.

Table 12 Benefit Costs Ratio (BCR) Off-farm Scenario

	CDSI	FD
Option A	1.01	1.12
Option B	0.90	1.01
Option C	0.96	1.05
Option D	0.94	1.00

4.4 SENSITIVITY ANALYSIS

As is evident from the historical data, crop prices are quite volatile. Also, crop yields vary greatly as they are dependent on several factors. Evidence from previous studies mentioned above points to the fact that these changes could affect the profitability of the water management system. Thus, a sensitivity analysis is performed to test the robustness of the results and assess how these changes may affect NPV.

The analysis conducted on the private BCA was conducted to ascertain how an increase or change in yields and crop prices might affect profitability. A 10% and 20% yield increase was assumed under the “farmer taking loan” scenario. The results showed that CDSI technology produces greater returns in the on-farm scenario.

The outcome of the sensitivity analyses reveal that CDSI is quite sensitive to yield changes, which is consistent with literature (See O’Brien et al, 1998; Lamm et al, 2003) that yield changes have a large impact on Economic analysis.

4.5 BREAK-EVEN ANALYSIS

Break even analysis was undertaken to determine the yield increase that the CDSI system needs in order for the CDSI revenue equals FD. It is sometimes referred to as the “Safety margin”. Table 13 below shows that for all the options (a – d) and with the different discount rates assumed, FD had a higher revenue advantage. In Option A, at a 3.75% discount rate, CDSI technology would have to produce an annual yield increase of 6.68% to bring out the same net returns as FD.

Table 13 Break even Analyses (Using NPV analysis using on Farm Scenario)

	CDSI	CDSI	CDSI
Discount rate	**3.75%**	**6.43%**	**8.47%**
Option A	6.68%	7.97%	8.94%
Option B	9.12%	9.99%	10.70%
Option C	6.55%	7.30%	7.89%
Option D	3.06%	3.60%	4.06%

CHAPTER 5

5.1 CONCLUSION AND RECOMMENDATION

The challenges associated with climate change and its link to global warming is increasingly becoming a subject of concern to society. Over the past decades, there has been an increase in the scientific literature that draw linkages between climate change and GHG emissions. In addition, government has educated the public on the potential impacts on the environment of increased GHG emissions, hence the resolve to engage in practices that engender a reduction in GHG emissions.

Based on literature, Controlled drainage with sub-irrigation technology has the potential to reduce nitrate loading in drainage water whilst simultaneously increasing yield. However, the need to assess GHG emissions that go into the atmosphere led to the research approach to estimate the quantity of GHG emissions that may escape from the soil in the form of N_2O, CO_2 and CH_4 under different water table management systems.

Although several studies support the positive impact that CDSI has on yield, there is not an abundance of literature assessing the economic effect of water table management systems, particularly in Quebec. There is a need to ascertain what policy options need to be explored to promote adoption, assuming that the CDSI technology also reduces atmospheric GHG emissions as it does with nitrate concentrations.

The objective of this project was to evaluate the economic impact of adopting the technology on the farm.

The profitability analysis demonstrated that CDSI produces net returns at a discount rate of 3.75% (which has a debt/equity ratio of 25:75 Statistics Canada, 2006). However, the net returns with the same discount rate are higher under the FD technology for Options A to D.

The project also showed that CDSI brought about an increase in atmospheric GHG emissions. This exacerbates the already increase in energy consumption for pumping water for irrigation.

The source of irrigation water for this project is supplied through the installation of a deep well as is customary in the region. Thus the analysis does not take into account the potential impacts of water price, water scarcity or restrictions on water property rights that may be affected by water resource challenges caused by climate change. The water problems are faced by farmers in many other regions of the world that suffer from seasonal droughts and unavailability of fresh water resource. These considerations work against the adoption of CDSI. Considering water constraints as a major problem may further deter the implementation of the CDSI technology based on the results above.

5.2. FURTHER RESEARCH

This section seeks to explore potential avenues for further research in the area. This research evaluated the impact of installing controlled drainage technology with sub-irrigation in Quebec and attempted to investigate the impact that technology has on greenhouse gas emissions and therefore climate change. A recent study (Crabbe et al 2012) in Ontario showed that controlled drainage increased farm profitability. Therefore, it would be interesting to investigate the impact of installing controlled drainage without sub-irrigation in Quebec in order to perform an economic comparison between controlled drainage with and without sub-irrigation, with field drainage as the control treatment. Also, it would be worthwhile to then evaluate the impact these three systems would have on greenhouse gas emissions.

Second, implementing irrigation systems on rain-fed or non-irrigated fields could have the potential to bring about a change in cropping patterns. It would be interesting to study the effect of implementing irrigation in the region and potential land use changes and/or changes in cropping patterns using mathematical programming methods. A major area of interest for AGGP is a reduction in GHG emissions, thus an evaluation of how these changes can affect emissions, profitability and more can be accommodated with this model.

Another area of interest for further research is to investigate thoroughly the role water balance data and future climate scenarios may play in determining the usefulness of an irrigation technology. This would give insight into the profitability of that system as well as throw light on the potential for a trade-off analysis where necessary between an increase in yields and profitability brought about by the technology and a potential increase in GHG gases.

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APPENDIX

Fixed Costs	Unit	Quantity	FD	CD	CDSI
Drainage tubing					
Piping			1046.71	1046.71	1046.71
Drainage land prep			36.45	36.45	36.45
Control Structure			0	87.10	87.10
Water Supply					
Deep well			0	0	113.7
Pump			0	0	407.17
Total investment Costs			1083.16	1170.26	1691.13
Depreciation			20.93	25.29	47.92
Loan Principal @75% financing			812.37	877.70	1268.35
Owners Equity			270.79	292.57	422.78
Opportunity Cost of Capital	2.19%		5.93	6.41	9.26
Interest on term loan	4.75%		103.93	112.29	162.27
Interest Costs			109.86	118.70	171.53
Variable costs					
Operating, Repairs & maintenance					
Pipes	0.25% of Investment		2.6	2.6	2.6
control structure	2% of annual AC		0	0.01	0.01
Deep well	None assumed		0	0	0
pump	1% of FC		0	0	4.1
	Total		2.62	2.63	6.70
***ALL VALUES INCLUDE INSTALLATION COSTS**					

Table 1 Breakdown of Costs for WTM assuming farmer takes loan

*Drainage tubing 150mm Diameter with filter, 15m drain spacing with a useful life of 50years						
<u>**Cost of system per hectare**</u>		Quantity (m)	with filter	per ac '09	FV per acre '14
100m	1.65$/m	601.6	992.6		
150m	5.30$/m	65.8	348.7		
200m (non perforated)	9.40$/m	1.5	14.1		
Joints			40.7		
Outlet (250m)			25.5		
<u>Installation</u>					
100m	1.25$/m	601.6	752.2		
150m	1.75$/m	65.8	115.2		
200m	2.40$/m	1.5	3.6		
Drainage prep		1ha	90		
TOTAL			2382.6	964.953	1046.71
AGDEX 752, Jan 2009 *updated 2012					
Average Inflation rate over the period=1.64% (Bank of Canada, 2014)					
<u>Cost of pipes inclusive of installation cost</u>					
*length/acre = area in m or feet/spacing in m or feet					
*This is based on amortizing the initial cost over 10yrs @6%					
Drainage Loan repayment period is typically over a 10 year span (Drainage Loan Calculator CRAAQ and OMAFRA)					
Insurance is excluded because most componenets of CDSI are underground					
Taxes are excluded					
Depreciation (Crabbe et al., 2012)					
Piping	50years	2%			
Control Structure	20years	5%			
Pump	20years	5%			
Deep Well	30years	2%			
Depreciation on structure = annual cost X rate of depreciation (Straight-line depreciation method)					

Table 2: This table shows a Breakdown of individual components WTMs and their costs -1

It is assumed the deep well has an expected life of 30years (Evans and Skaggs, 1996) and was constructued for use on			
Deep well	per hectare	per acre	
5615.4	280.8	113.7	
divided by no of hectares			
Pump			
4021.4	1005.35	407.17	
Control			
860.3	215.075	87.105375	
Amortization factor for 20yrs @ 4.75	0.006462236	figure derived from amortization factor table	
Annual cost =	0.562895516	per acre	
Annual operating costs	0.01		
1 control structure is used for 4ha with an expected life of 20 yrs (Agri Drain Corporation, 2010) and 5% depreciation			
The cost of the control structure on the site was CAD$ 741 in 1992 = using the FV formula, cost is CAD$860.30 in 2012.			
Cost of control in 2006 is CAD$840 (Crabbe e al., 2012) cost inclusive of non-perforated pipe			
Opportunity Cost of Capital (OCC)= Amount earned if farmer saved the investment funds in a GIC			
*GIC (Guaranteed Investment Certificate) = 2.19%-10yr average, assuming 5yr fixed GIC (Bank of Canada, 2015)			
Average bank interest rate over the period = 2005 - 2015 =2.04(Bank of Canada, 2015)			
Fuel, Lube and Labor are included in maintenance and operating costs			
$90/ha for preparing land for underground drainage = $36.45/acre			
Cost of Deep Well is $5615.35 (Future Value)			
Cost of Pump is $4021.4 (Future Value, using AGDEX 754, CRAAQ, 2010) Installation included. 1HP for 4ha			
*5 yr Conventional Mortgage, 10 year average = 5.75 (2006-2015) Bank of Canada, 2016			
Prime Lending rate (Meduim Term Outlook, 2015)			
2015-2024 Average	2015-2019	2020-2024	
4.75%	3.80%	5.70%	

Table 3: The table shows a Breakdown of individual components WTMs and their costs -2

	Unit	2014 Quantity	Price (CAD$)	Corn-FD	2014 Quantity	Price (CAD$)	Corn-CD
Yield (tonnes/acre)		3.87	197.05	762.58	3.92	197.05	772.44
Other gov't payments		1	0	0.00	1	0	0.00
Gross revenue				762.58			772.44
Variables Cost							
Seed		1	118.62	118.62	1	118.62	118.62
Inorganic (N, P2O5, K2O)		1	170.04	170.04	1	170.04	170.04
limestone		1	13.85	13.85	1	13.85	13.85
Herbicides		1	11.74	11.74	1	11.74	11.74
Crop insurance		1	17.00	17.00	1	17.00	17.00
*Custom Work		1	20.00	20.00	1	20.00	20.00
Drying		1	63.68	63.68	1	63.68	63.68
Storage ($2.06/tonne/month *4months)		1	4.86	4.86	1	4.86	4.86
Trucking and Vehicle ($9.06/tonne)		1	30.65	30.65	1	30.65	30.65
*Misc (mrkt fees)		1	15.00	15.00	1	15.00	15.00
Fuel, lube and electricity		1	23.60	23.60	1	23.60	23.60
Mach repair & Maint.		1	16.00	16.00	1	16.00	16.00
Bldg. Repair & Maint.		1	0.00	0.00	1	0.00	0.00
Labour		1	15.50	15.50	1	15.50	15.50
Interest on Operating Capital rate @5%		1	9.30	9.30	1	9.30	9.30
Total Variable costs				529.84			529.84
Land rent		1	0.00	0.00	1	0.00	0.00
Building		1	0.00	0.00	1	0.00	0.00
Interest on Loan	5%	1	13.05	13.05	1	13.05	13.05
Depreciation		1	28.45	28.45	1	28.45	28.45
Total Fixed costs				41.50			41.50
Water Management system							
Investment Costs		1	0	0.00	1	0	0.00
Annual Operating Costs		1	0.00	0.00	1	0.00	0.00
Total Production Costs				571.34			571.34
Production Costs				282.68			
Net Farm Returns				191.24			201.10

Table 4 Corn budgets 2014 for St. Emmanuelle

option a	Normal Distribution					
	CDSI (t/ha)	FD (t/ha)	Crop Price	Seeds	Fertilizer	Prdtn Costs
2015	10.41	11.52	**169**	**120.28**	**165.28**	**282.40**
2016	9.88	9.24	**187**	**123.05**	**166.93**	**287.48**
2017	10.04	11.3	**188**	**126.12**	**169.94**	**293.81**
2018	10.1	9.85	**200**	**129.02**	**175.37**	**301.74**
2019	11.25	9.9	**201**	**132.25**	**181.34**	**310.49**
2020	10.62	11.56	**199**	**135.03**	**182.97**	**315.77**
2021	10.97	9.35	**201**	**137.86**	**186.45**	**322.40**
2022	11.8	11.74	**198**	**140.90**	**189.43**	**328.85**
2023	11.36	10.46	**199**	**143.71**	**191.13**	**334.11**
2024	9.57	11.46	**199**	**146.59**	**192.66**	**339.45**
2025	9.38	8.52	261	142.05	168.55	307.9
2026	10.51	9.93	224	139.38	174.1	291.3
2027	10.23	9.38	181	130.2	180.71	265.43
2028	10.62	9.78	178	134.3	177.64	292.51
2029	9.92	9.63	171	135.67	184.57	306.68
2030	10.66	9.96	169	122.25	180.33	286.85
2031	12.26	12.37	225	136.22	174.24	275.06
2032	10.72	9.5	258	139.92	196.96	286.17
2033	9.52	8.24	224	138.01	172.61	277.64
2034	9.49	9.34	195	131.92	195.19	274.88

Table 5 Shows Medium Term Outlook values in bold (2015 – 2024) and Random number generator Results Option A (2025-2034)

Cost for Corn per acre																						
	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	
PROJECT NET CASH FLOW																						
ITEM/YEAR	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	
Investment costs CDSI																						
Fixed Investment	422.78	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
System Annual Cost	0	219.45	219.45	219.45	219.45	219.45	219.45	219.45	219.45	219.45	219.45	47.92	47.92	47.92	47.92	47.92	47.92	47.92	47.92	47.92	47.92	
Variable costs	0	6.81	6.92	7.03	7.15	7.27	7.39	7.51	7.63	7.76	7.88	8.01	8.14	8.28	8.41	8.55	8.69	8.83	8.98	9.13	9.28	
Total Cost of System	**-422.78**	**-226.26**	**-226.37**	**-226.48**	**-226.60**	**-226.72**	**-226.84**	**-226.96**	**-227.08**	**-227.21**	**-227.33**	**-55.93**	**-56.07**	**-56.20**	**-56.33**	**-56.47**	**-56.61**	**-56.76**	**-56.90**	**-57.05**	**-57.20**	**-3256.14**
Investment Costs FD																						
Fixed Investment	270.79	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
System annual Costs	0	130.80	130.80	130.80	130.80	130.80	130.80	130.80	130.80	130.80	130.80	20.93	20.93	20.93	20.93	20.93	20.93	20.93	20.93	20.93	20.93	
Variable costs	0	2.66	2.70	2.75	2.79	2.84	2.89	2.93	2.98	3.03	3.08	3.13	3.18	3.23	3.29	3.34	3.39	3.45	3.51	3.56	3.62	
Total Cost of system	**-270.79**	**-133.46**	**-133.50**	**-133.54**	**-133.59**	**-133.64**	**-133.68**	**-133.73**	**-133.78**	**-133.83**	**-133.88**	**-24.06**	**-24.12**	**-24.17**	**-24.22**	**-24.27**	**-24.33**	**-24.38**	**-24.44**	**-24.50**	**-24.56**	**-1850.46**
Seed	0	118.62	120.28	123.05	126.12	129.02	132.25	135.03	137.86	140.90	143.71	146.59	142.05	139.38	130.20	134.30	135.67	122.25	136.22	139.92	138.01	
Fertillizer	0	170.04	165.28	166.93	169.94	175.37	181.34	182.97	186.45	189.43	191.13	192.66	168.55	174.10	180.71	177.64	184.57	180.33	174.24	196.96	172.61	
Procduction costs	0	282.68	282.40	287.48	293.81	301.74	310.49	315.77	322.40	328.85	334.11	339.45	307.90	291.30	265.43	292.51	306.68	286.85	275.06	286.17	277.64	
Total Production	0	**-571.34**	**-567.96**	**-577.46**	**-589.86**	**-606.14**	**-624.08**	**-633.76**	**-646.71**	**-659.17**	**-668.95**	**-678.70**	**-618.50**	**-604.78**	**-576.34**	**-604.45**	**-626.92**	**-589.43**	**-585.52**	**-623.05**	**-588.26**	**-12241.37**
Total Costs																						**Costs**
CDSI	**-422.78**	**-797.60**	**-794.33**	**-803.94**	**-816.46**	**-832.85**	**-850.91**	**-860.72**	**-873.79**	**-886.38**	**-896.29**	**-734.64**	**-674.56**	**-660.98**	**-632.67**	**-660.92**	**-683.54**	**-646.18**	**-642.42**	**-680.10**	**-645.46**	15497.52
PV Costs	**-422.78**	**-749.41**	**-701.25**	**-666.86**	**-636.33**	**-609.89**	**-585.46**	**-556.43**	**-530.75**	**-505.87**	**-480.62**	**-370.14**	**-319.34**	**-294.00**	**-264.41**	**-259.53**	**-252.19**	**-224.01**	**-209.25**	**-208.14**	**-185.60**	9032.29
FD	-270.79	-704.80	-701.46	-711.00	-723.45	-739.77	-757.76	-767.49	-780.48	-793.00	-802.83	-702.77	-642.61	-628.94	-600.56	-628.72	-651.25	-613.81	-609.96	-647.55	-612.82	14091.83
PV Costs	-270.79	-662.22	-619.26	-589.77	-563.84	-541.72	-521.37	-496.16	-474.08	-452.58	-430.51	-354.08	-304.22	-279.76	-250.99	-246.89	-240.28	-212.79	-198.68	-198.18	-176.22	8084.37
Revenues																						**Benefits**
CDSI	0	772.44	712.51	747.99	764.74	818.13	915.74	855.72	892.67	946.24	915.56	771.01	954.37	955.38	751.02	764.17	769.21	817.20	1119.80	1120.02	863.23	**17227.16**
PV Revenue	**0**	**725.77**	**629.02**	**620.44**	**596.01**	**599.11**	**630.07**	**553.20**	**542.23**	**540.04**	**490.96**	**388.47**	**451.80**	**424.95**	**313.87**	**300.08**	**283.81**	**283.30**	**364.74**	**342.77**	**248.23**	**9328.87**
FD	0	762.58	788.33	699.94	860.64	797.85	805.55	931.87	761.01	941.77	843.05	923.65	866.87	902.62	688.44	703.67	746.81	763.73	1129.64	992.44	747.16	**16657.66**
PV Revenue	**0.00**	**716.51**	**695.95**	**580.59**	**670.76**	**584.26**	**554.26**	**602.43**	**462.25**	**537.49**	**452.08**	**465.38**	**410.38**	**401.49**	**287.72**	**276.32**	**275.54**	**264.76**	**367.95**	**303.73**	**214.85**	**9124.68**
Net Cash Flow																						
CDSI	**-422.78**	**-25.16**	**-81.81**	**-55.96**	**-51.73**	**-14.72**	**64.83**	**-5.00**	**18.89**	**59.87**	**19.27**	**36.37**	**279.81**	**294.40**	**118.35**	**103.25**	**85.68**	**171.02**	**477.38**	**439.92**	**217.77**	**1729.64**
NPV	-422.78	-23.64	-72.23	-46.41	-40.31	-10.78	44.61	-3.23	11.47	34.17	10.33	18.32	132.46	130.95	49.46	40.54	31.61	59.29	155.49	134.64	62.62	**296.58**
FD	**-270.79**	**57.79**	**86.87**	**-11.06**	**137.19**	**58.08**	**47.80**	**164.38**	**-19.47**	**148.78**	**40.22**	**220.89**	**224.26**	**273.68**	**87.88**	**74.94**	**95.56**	**149.92**	**519.68**	**344.89**	**134.35**	**2565.83**
NPV	-270.79	54.30	76.69	-9.17	106.92	42.53	32.89	106.27	-11.83	84.91	21.57	111.29	106.16	121.73	36.73	29.43	35.26	51.97	169.27	105.55	38.63	**1040.31**

CDSI			
Discount rate	**3.75%**	**6.43%**	**8.47%**
Net Present Value	**713.12**	**296.6**	**82.2**
IRR	**2.86%**		
Benefit-Cost Ratio	**1.07**	**1.03**	

FD			
Discount rate	**3.75%**	**6.43%**	**8.47%**
Net Present Value	**1501.5**	**1040.3**	**791.3**
IRR	**20.51%**		
Benefit Cost Ratio	**1.15**	**1.13**	

Table 6 Detailed Private NPV Analysis Assuming Loan Scenario Option A

Cost for Corn per acre																						
	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	
PROJECT NET CASH FLOW																						
ITEM/YEAR	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	
Investment costs CDSI																						
Fixed Investment	1691.13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
System Annual Cost	0	84.96	84.96	84.96	84.96	84.96	84.96	84.96	84.96	84.96	84.96	47.92	47.92	47.92	47.92	47.92	47.92	47.92	47.92	47.92	47.92	
Variable costs	0	6.81	6.92	7.03	7.15	7.27	7.39	7.51	7.63	7.76	7.88	8.01	8.14	8.28	8.41	8.55	8.69	8.83	8.98	9.13	9.28	
Total Cost of System	**-1691.13**	**-91.77**	**-91.88**	**-91.99**	**-92.11**	**-92.22**	**-92.34**	**-92.47**	**-92.59**	**-92.71**	**-92.84**	**-55.93**	**-56.07**	**-56.20**	**-56.33**	**-56.47**	**-56.61**	**-56.76**	**-56.90**	**-57.05**	**-57.20**	**-3179.57**
Investment Costs FD																						
Fixed Investment	1083.16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
System annual Costs	0	44.66	44.66	44.66	44.66	44.66	44.66	44.66	44.66	44.66	44.66	20.93	20.93	20.93	20.93	20.93	20.93	20.93	20.93	20.93	20.93	
Variable costs	0	2.66	2.70	2.75	2.79	2.84	2.89	2.93	2.98	3.03	3.08	3.13	3.18	3.23	3.29	3.34	3.39	3.45	3.51	3.56	3.62	
Total Cost of system	**-1083.16**	**-47.32**	**-47.36**	**-47.40**	**-47.45**	**-47.49**	**-47.54**	**-47.59**	**-47.64**	**-47.68**	**-47.73**	**-24.06**	**-24.12**	**-24.17**	**-24.22**	**-24.27**	**-24.33**	**-24.38**	**-24.44**	**-24.50**	**-24.56**	**-1801.41**
Seed	0	118.62	120.28	123.05	126.12	129.02	132.25	135.03	137.86	140.90	143.71	146.59	142.05	139.38	130.20	134.30	135.67	122.25	136.22	139.92	138.01	
Fertillizer	0	170.04	165.28	166.93	169.94	175.37	181.34	182.97	186.45	189.43	191.13	192.66	168.55	174.10	180.71	177.64	184.57	180.33	174.24	196.96	172.61	
Procduction costs	0	282.68	282.40	287.48	293.81	301.74	310.49	315.77	322.40	328.85	334.11	339.45	307.90	291.30	265.43	292.51	306.68	286.85	275.06	286.17	277.64	
Total Production	**0**	**-571.34**	**-567.96**	**-577.46**	**-589.86**	**-606.14**	**-624.08**	**-633.76**	**-646.71**	**-659.17**	**-668.95**	**-678.70**	**-618.50**	**-604.78**	**-576.34**	**-604.45**	**-626.92**	**-589.43**	**-585.52**	**-623.05**	**-588.26**	**-12241.37**
Total Costs																						**Costs**
CDSI	**-1691.13**	**-663.11**	**-659.84**	**-669.45**	**-681.97**	**-698.36**	**-716.42**	**-726.23**	**-739.29**	**-751.88**	**-761.79**	**-734.64**	**-674.56**	**-660.98**	**-632.67**	**-660.92**	**-683.54**	**-646.18**	**-642.42**	**-680.10**	**-645.46**	15420.95
PV Costs	**-1691.13**	**-623.05**	**-582.52**	**-555.30**	**-531.51**	**-511.40**	**-492.93**	**-469.49**	**-449.06**	**-429.12**	**-408.50**	**-370.14**	**-319.34**	**-294.00**	**-264.41**	**-259.53**	**-252.19**	**-224.01**	**-209.25**	**-208.14**	**-185.60**	9330.62
FD	-1083.16	-618.66	-615.32	-624.86	-637.31	-653.63	-671.62	-681.35	-694.34	-706.85	-716.69	-702.77	-642.61	-628.94	-600.56	-628.72	-651.25	-613.81	-609.96	-647.55	-612.82	14042.78
PV Costs	-1083.16	-581.28	-543.21	-518.31	-496.70	-478.64	-462.10	-440.48	-421.76	-403.42	-384.32	-354.08	-304.22	-279.76	-250.99	-246.89	-240.28	-212.79	-198.68	-198.18	-176.22	8275.45
Revenues																						**Benefits**
CDSI	0	772.44	712.51	747.99	764.74	818.13	915.74	855.72	892.67	946.24	915.56	771.01	954.37	955.38	751.02	764.17	769.21	817.20	1119.80	1120.02	863.23	**17227.16**
PV Revenue	**0**	**725.77**	**629.02**	**620.44**	**596.01**	**599.11**	**630.07**	**553.20**	**542.23**	**540.04**	**490.96**	**388.47**	**451.80**	**424.95**	**313.87**	**300.08**	**283.81**	**283.30**	**364.74**	**342.77**	**248.23**	**9328.87**
FD	0	762.58	788.33	699.94	860.64	797.85	805.55	931.87	761.01	941.77	843.05	923.65	866.87	902.62	688.44	703.67	746.81	763.73	1129.64	992.44	747.16	**16657.66**
PV Revenue	**0.00**	**716.51**	**695.95**	**580.59**	**670.76**	**584.26**	**554.26**	**602.43**	**462.25**	**537.49**	**452.08**	**465.38**	**410.38**	**401.49**	**287.72**	**276.32**	**275.54**	**264.76**	**367.95**	**303.73**	**214.85**	**9124.68**
Net Cash Flow																						
CDSI	**-1691.13**	**109.33**	**52.68**	**78.54**	**82.77**	**119.77**	**199.32**	**129.50**	**153.38**	**194.36**	**153.76**	**36.37**	**279.81**	**294.40**	**118.35**	**103.25**	**85.68**	**171.02**	**477.38**	**439.92**	**217.77**	**1806.21**
NPV	-1691.13	102.72	46.50	65.14	64.50	87.71	137.14	83.72	93.17	110.92	82.45	18.32	132.46	130.95	49.46	40.54	31.61	59.29	155.49	134.64	62.62	**-1.76**
FD	**-1083.16**	**143.93**	**173.01**	**75.08**	**223.33**	**144.22**	**133.94**	**250.52**	**66.67**	**234.92**	**126.37**	**220.89**	**224.26**	**273.68**	**87.88**	**74.94**	**95.56**	**149.92**	**519.68**	**344.89**	**134.35**	**2614.87**
NPV	-1083.16	135.23	152.74	62.28	174.05	105.61	92.16	161.95	40.50	134.07	67.76	111.29	106.16	121.73	36.73	29.43	35.26	51.97	169.27	105.55	38.63	**849.23**
CDSI								**FD**														
Discount rate	**3.75%**	**6.43%**	**8.47%**					**Discount rate**			**3.75%**	**6.43%**	**8.47%**									
Net Present Value	**549.32**	**-1.8**	**-302.6**					**Net Present Value**			**1396.5**	**849.2**	**544.9**									
IRR	**-0.01%**							**IRR**			**7.30%**											
Benefit-Cost Ratio		**0.9998**						**Benefit Cost Ratio**				**1.10**										

Table 7 Detailed Public NPV Analysis Assuming No Loan Scenario Option A