Agricultural Climate Change Impacts and Vulnerabilities in the Essex Region

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Introduction

Farmers are used to planning for uncertainty and are probably the most adaptive workers in any sector. They are astute observers of weather and they adapt to changes on a daily, weekly, and seasonal basis. Climate change will to bring both challenges and opportunities for farmers. While extreme climate variables like high temperatures and extreme precipitation will continue to challenge farmers in the Essex region into the future, longer growing seasons will provide longer periods in which crops may mature which may result in higher, more productive yields.

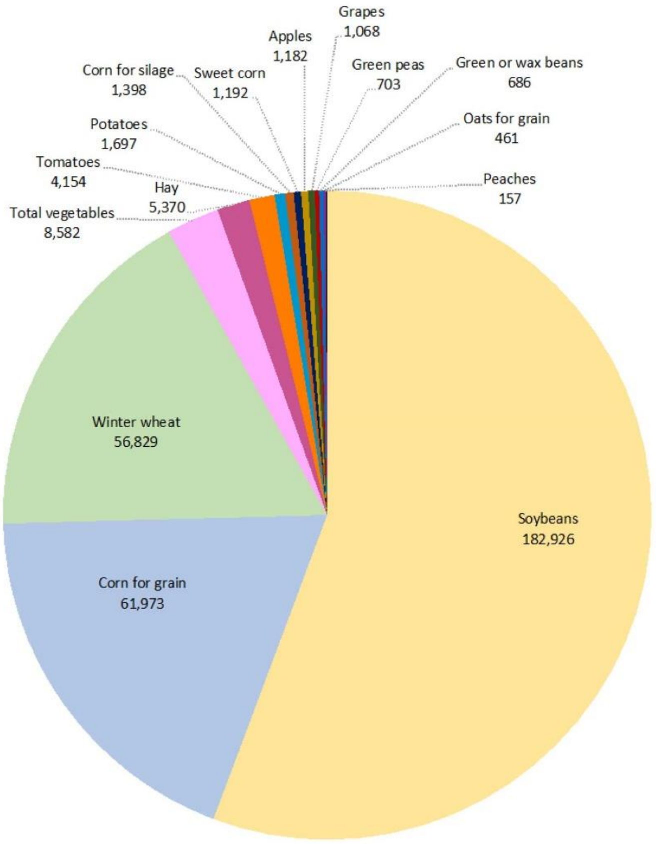
This report explores the potential impacts of changes in growing season length, precipitation, and temperature to the agricultural sector in the Essex region. Exploring these changes allows recommendations to be made to all stakeholders, including farmers, researchers, and government, in order to maintain high levels of agricultural productivity in the region in a changing climate. Understanding current and future climate impacts to agricultural yields and environmental changes can help this region perhaps be more competitive for future government funding support. Additionally, as a conservation agency, we can use climate change as a driver for change because of the expected economic benefits, the anticipated improvements in soil quality and improvements in biodiversity that suggested adaptation actions would bring.

The literature review in this report was undertaken by graduate students in the Masters in Environment and Sustainability (MES) program in the Centre for Environment and Sustainability (CES) at Western University, London, Ontario. Due to Covid-19, engagement was done through virtual meetings. A summary of these engagement events can be found in the appendix.

Agricultural Profile of the Essex Region

The Essex region is home to a thriving agricultural industry. Located in the southern tip of Ontario, the climate allows for one of the longest growing seasons in Canada (Arend, 2017). With around 80% of the region’s land belonging to the agriculture sector, the Essex region leads Ontario in gross domestic product (GDP) generated by agriculture at $1.2 billion (McRae et al., 2015). According to the 2016 Census of Agriculture, land use for crops in the Essex region covers approximately 328,000 acres. The majority of this acreage consists of soybeans at 182,926 acres, followed by corn and winter wheat at 61,973 and

56,829 acres respectively (Statistics Canada, 2016abc; (Figure 1.). The Essex region also has the most intensive greenhouse growing area in Canada, covering over 4290 acres in Leamington and Kingsville alone and across the region, the greenhouse sector continues to grow at an accelerated rate (Hill, 2020). However, climate in the Essex region also allows for diverse fruit production, including apples, grapes, peaches and strawberries (ECFA, 2015).



Crop	Total Farm Acerage
Soybeans	182,926
Corn for Grain	61,973
Winter Wheat	56,829
Total Vegetables	8,582
Hay	5,370
Tomatoes	4,154
Potatoes	1,697
Corn for silage	1,398
Sweet Corn	1,192
Apples	1,182
Grapes	1,068
Green Peans	703
Green or Wax beans	686
Oats for Grain	461
Peaches	157

Figure 1. Total farm acreage by crop in the Essex region (Census of Agriculture 2016, Table: 32-10-0416-01, Table: 32-10-0417-01, Table: 32-10-0418-01)

Between the 2011 and 2016 Census, fruit acreage declined the greatest with all varieties decreasing between 10-40%, while tomato acreage decreased by approximately 10% (Statistics Canada, 2016bc). In contrast, soybean acreage increased by approximately 14% as well as corn and oats for grain by 16% and

180% respectively. (Statistics Canada, 2016a). These changes may be attributed to increasing temperatures throughout the region as corn and soybean varieties are able to withstand higher soil temperature, while high air temperatures can prevent flowering crops from producing fruit. It is important to note that these changes may also be attributed to the 2014 closure of the Leamington Heinz factory (Pearson, 2014). As the decreased demand for field tomatoes in the region likely caused farmers to change crops. While socioeconomic factors such as crop demand play a role in the regions agricultural productions, gaining a better understanding how climate change is expected to impact the agriculture sector of the Essex region is needed to support climate change adaptation efforts by the region.

Summary of Climate Projections

The data used for the projections within this report was accessed from Climate Atlas of Canada. The Climate Atlas is operated by the Prairie Climate Centre and is funded by Environment and Climate Change Canada (ECCC). Climate change projections are quantified through various metrics within four climate change indicators: temperature, precipitation, agriculture, and hydrology. Projections for each metric are provided for the time scales of 2021-2050 and 2051-2100. Projections are also considered for the two global carbon emissions scenarios, which were developed by the Intergovernmental Panel on Climate Change (IPCC). The main source of climate modelling data used for projections for the Climate Atlas is the Pacific Climate Impacts Consortium (PCIC). PCIC created models using data collected from meteorological sites across Canada operated by Natural Resources Canada. The data was statistically downscaled by ECCC to remove systematic bias as much as possible and to create high-resolution data.

The two carbon emissions scenarios are classified under the global standard of Representative Concentration Pathways (RCP) from the IPCC.

- RCP 8.5: High-carbon or business-as-usual scenario
- RCP 4.5: Low-carbon or carbon reduction scenario

Under the RCP 8.5 scenario, we can expect:

Increased temperature all year round. Average, maximum, and minimum temperatures are expected to increase by 22% (2.1°C) by 2050.

Winter is projected to experience the largest seasonal increase in temperature, as much as 2.3°C by 2050. This will result in fewer frost days and longer growing seasons among other agriculturally important metrics. Summer temperatures are also projected to increase in temperature as much as 2.1°C by 2050.

Increased precipitation all year round. The largest increases in precipitation are expected during the spring and winter months, specifically December, January, February, March, and April. Precipitation in March is expected to increase by as much as 13% (8 mm) by 2050. Fall and summer months are expected to see small increases in precipitation.

Spring is expected to stay the wettest season of the year. In the recent past (1976-2005), the average spring (219 mm) and summer (220 mm) total precipitation was almost equal. However, over the course of the century, spring is expected to see one of the largest increases in precipitation (16%), while summer is expected to see the lowest increase (1%).

Growing season is expected to increase in duration in the future. In the recent past (1976-2005), the average growing season length for the Essex Region was 194 days. The growing season is expected to increase by 21% (41 days) by 2050.

Frost and ice days are expected to decrease considerably in the future. In the recent past (1976-2005), the Essex Region experienced 117 frost days and 45 ice days. By 2050, the number of frost days is expected to decrease by 22% (25 days) and the number of ice days is expected to decrease by 35% (29 days).

Impacts of Changing Temperature & Precipitation Regimes

Chapter 1.

Crop Growth and Development (Yields)

Temperature directly affects the rate of plant, or crop growth and development (Hatfield & Prueger, 2015). Every species of plant has a temperature range where normal growth and development occurs. Within the range is an optimal temperature that results in the highest rate of growth and development, or greatest yield (Hatfield & Prueger, 2015). With an anticipated increase of at least 2°C by 2050 and 4°C by 2080 (Essex Climate Projections Report, 2020), the yields of crops in the Essex region will drastically change. Studies have predicted a yield reduction of up to 10% for many crop species (soybean, wheat, etc.) by the end of the 21st century (Hatfield & Prueger. 2015).

Every crop species will respond differently to increased temperatures and there can also be a variety of responses within a crop species depending on which life cycle stage the crop is in. Vegetative development which includes node and leaf appearance rate, usually increases in rate at a plant’s optimum temperature (Hatfield & Prueger, 2015). It is also worth noting that vegetative development typically has a higher optimum temperature than a plant’s reproductive rate (Streck, 2015). If a plant develops faster, it will generally have a shorter life cycle, be smaller and have lower yield potential (Streck, 2005). In summary, major temperature changes even for short periods of time, can significantly impact yields and productivity.

It is important to know that annual crops and perennial crops react differently to temperature changes (Hatfield & Prueger, 2015). Annual crops will experience decreased yields once a temperature rises beyond the crop’s optimal temperature. However, the decrease is not constant as temperature increases, the yield loss will accelerate as the temperature surpasses optimal temperature. To be more specific, plants subjected to temperatures 1-4°C above optimal will experience moderately reduced yields while plants subjected to temperatures more than 4°C above optimal will experience severely reduced yields (Hatfield & Prueger, 2015).

Perennial crops do not need to be planted each year and include most fruits (apples, grapes, etc.) and some vegetables. The response of a perennial crop to increased temperatures is generally more complex than annual crops (Hatfield & Prueger, 2015). This is largely because many perennial crops have a chilling requirement where the plant must be subjected to temperatures below a certain threshold (varies by species) before the plant can begin flowering (Atkinson et al., 2013). Increased temperatures, especially in the winter may prevent the required amount of chilling time to take place and prevent the growth of perennial plants (Atkinson et al., 2013). Similar to annual crops, perennial plants also can suffer reduced or lower quality yields due to higher temperature conditions (Hatfield & Prueger, 2015). For example, some apple species will be bigger at temperatures above 22°C but will be less firm. Crop species will respond differently to temperature related stress, but the result will usually be reduced yield in some capacity (Hatfield & Prueger, 2015).

Extreme temperatures, even short periods, can disrupt the development process of plants and cause a reduced or lost yield. Every plant handles extreme temperatures differently; however, the resulting effect is almost always a negative. Generally, higher minimum temperatures negatively affect crop yield by shortening the time it takes for a plant to reach maturity (Hatfield & Prueger, 2015). As a plant ages, the productivity of the plant decreases, which is often called senescence (Hatfield & Prueger, 2015). However, productivity can be unaffected if the temperature increase occurs during certain stages of the plant's life cycle. Furthermore, accelerated maturation and reduced productivity also can occur when night temperatures are increased (Hatfield & Prueger, 2015; Singh et al., 1998). In conclusion, temperature is an essential factor during plant development and non-optimal temperatures for long periods of time can limit or even stop plant growth.

Growing Season

It is expected that climate change will bring about warmer temperatures year-round globally and within the Essex region (IPCC, 2013; Table 1.). As such, the growing season is expected to increase between 16 to 19 days by the year 2050 (PCC, 2019). A longer growing season will result in a larger number of growing degree days and decreased number of frost days and ice days. Increases in these metrics ultimately affect the growing season length; however, growing season is a broad topic explored within this section, with references made back to these specific metrics. An increase in growing season will bring about both positive as well as negative changes for the growth of all crops. A longer growing season could boost crop yield and present other opportunities for different species to be grown in the region (Harris et al., 2016). It may also bring about more frequent heat waves and droughts in the summer which will be damaging to some crops due to increased risk of these weather events occurring. (Harris et al., 2016).

RCPs	Time Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
(baseline)	Recent Past	- 4.3	-3.0	1.6	8.2	14.4	20.0	22.6	21.6	17.8	11.6	5.0	- 1.0
RCP 4.5	2021-2050	- 2.0	-1.1	3.3	9.8	16.2	21.6	24.4	23.6	20.0	13.4	6.9	0.9
RCP 4.5	2051-2080	- 0.9	0.3	4.1	10.6	17.1	22.6	25.5	24.6	20.9	14.2	7.6	1.9
RCP 8.5	2021-2050	- 1.9	-0.6	3.4	9.8	16.3	21.9	24.8	24.0	20.3	13.7	6.9	1.1
RCP 8.5	2051-2080	0.3	1.4	5.2	11.7	18.2	23.8	27.0	26.2	22.4	15.7	8.7	3.3

Table 1. Average Monthly Temperature (°C) for the Essex region. Data from Climate Atlas (2020).

Projections of longer growing seasons could result in increasing need for irrigation, alternative water supplies and storage in order to support agricultural needs (Betts, 2005). This is due to a more variable water supply and longer warm temperature periods associated with a longer growing season resulting in more effective evapotranspiration. An increased growing season could result in farmers being able to plant and harvest crops earlier in the year than in the past (Harris et al., 2016). This would be beneficial only if other climate variables remain favourable for crops throughout the season. For instance, increased growing seasons may provide longer opportunities for crops to mature; however, if extreme rainfall or heat waves occur during this growing season, the predicted gains in yield from an extended growing season will be lost (Harris et al., 2016). These impacts will be highly variable and hard to predict, particularly because crops respond differently to changes in conditions based on their crop type and the stage of development that they are in. In addition, tillage practices by farmers may need to be adjusted in order to adapt or take advantage of the changing climate. For example, as extreme weather events become more frequent, farmers may choose to leave crop residue on fields in order to reduce the risk of soil erosion and plant nutrient altering (Harris et al., 2016).

Fall Hardening

Fall hardening is the process by which plants adapt to winter temperatures by storing nutrients and water in protected winter storage organs (Bélanger et al., 2006). Climate change is expected to decrease the length of the winter period and as such, this could lead to shorter periods for plants to undergo fall hardening (Bélanger et al., 2006). This may result in plants that are more susceptible to cold temperatures, especially if these changes are abrupt. Climate change is expected to increase temperature variability and as such plant species may be more at risk for damage caused by sudden drops in temperature in the future (Bélanger et al., 2006). Furthermore, the climate is also expected to become wetter in the future which may further impact fall hardening as increased soil moisture prevents plants from reaching their full hardening potential in the fall (Bélanger et al., 2006).

Winter Thaw

Another impact that an elongated growing season will result in is an earlier winter thaw period. This earlier thaw period will cause shifting growing seasons that farmers will have to take note of as the blooming season will be shifted forward in the future. Earlier spring thaws will also result in overall higher soil temperatures, which may result in decreasing permafrost cover, as well as increased releases of nitrogen dioxide (Pattey et al., 2008). Nitrogen dioxide is produced in frozen soil that thaws due to microbial decomposition of nutrients that were previously locked away within the soil. This release of nitrogen dioxide has negative consequences pertaining to global warming as it is more efficient at warming the climate than carbon dioxide (Pattey et al., 2008). The release of the nitrogen dioxide may be negated in the distant future however, as less soil will be frozen and permafrost will be less prevalent due to increasing global temperatures and decreasing winter seasons; this may in turn result in fewer freeze-thaw cycles, and thus less nitrogen dioxide produced (Pattey et al., 2008). This effect is not expected to be of significant concern for the Essex Region due to the short winters experienced, however may still have slight impacts on nitrogen dioxide releases.

Floods

Increased precipitation in the winter and spring can lead to flooding and waterlogging of agricultural fields during the spring season (PCC, 2019). Flooding conditions occur when there is a temporary overflow of water on land that is normally dry. However, waterlogging occurs when water enters the soil at a faster rate than it can be drained which can be caused by heavy rainfall, flooding, or a high-water table (Hardy et al., 2012). The extent and duration of waterlogging and flooding conditions are highly dependent on the land’s characteristics including the soil profile and topography of the region.

The Essex region consists mainly of clay-based soils (LIO, 2017), which cause very slow water movement through the soil, increasing incidences of saturation. This may exacerbate waterlogging and flooding conditions that result from increased precipitation causing even greater damages to fields and crops. When agricultural fields become waterlogged, the oxygen supply in the soil is depleted. This means that there is very little, or no oxygen available for the root zone of the crop which directly causes damage to the plant (Russell, 1977). Inhibited root development, leaf loss and even plant death can all be a result of prolonged flooding conditions and waterlogged soils (Linkemer et al., 1998; Minchin & Pate, 1975). Short-term flooding may not result in significant damages to crops and can potentially even improve crop yields in some cases. For example, a study conducted on soybeans showed that short flooding conditions lasting between 2 to 4 days increased soybean yields (Rhine et al., 2010). Apart from the physical damage to the crop, flooding conditions may also prevent farmers from planting or harvesting crops, effectively shortening the growing season as a delay in planting increases the probability of the crop not maturing on time (Reid et al., 2007).

Flooding conditions resulting from increased precipitation can also cause soil erosion and the leaching of nutrients from soil (Hammad et al., 2006). Both of these processes impact the availability of nutrients in the soil that are required for plant growth. Soil loss due to erosion carries with it the nutrients and organic matter that would otherwise have been available for crops. Water soluble nutrients such as phosphates and nitrates can be leached from agriculture soil during flooding conditions and into other local water sources (Clark, 2019). Nutrient loss will decrease crop yields as plants will not be getting the nutrients needed for development or survival. Furthermore, it can also increase the amount of fertilizer and pesticides required by the farmer to compensate for these losses (Clark, 2019).

Another consequence of extended flooding conditions on agriculture is the possible increased incidences of insects, diseases, and pests. The impacts of climate change are expected to increase the survival and reproduction rates of certain insects, pests and diseases (Crawford & MacNair, 2012). One possible species of concern in North America is the western corn rootworm. This insect thrives in the wet spring season and is known to have devastating impacts on corn yields, decreasing them by as much as 13% (Apple et al., 1977). Excessive spring moisture can also accelerate weed growth, increasing crops' competition for light and nutrients (McDonald et al., 2009).

Droughts

By the end of the century, the Essex region is expected to receive almost no change in the precipitation (< 5 mm) during the summer months (PCC, 2019). This, combined with increased temperature, is predicted to increase the drought conditions during the summer growing season. Drought conditions occur when there is a period of unusually dry weather that lasts long enough to cause a hydrological imbalance (IPCC, 2013). When these drought conditions occur during the growing season, they can have negative impacts on crop production by limiting the amount of moisture availability in the soil. This alone will impact a crop's growth and development; however, decreases in soil moisture also impact the crop's ability to uptake important soil nutrients such as nitrogen and phosphorous (Rouphael et al., 2012). Lack of nutrients combined with the lack of water requirements can lead to significant decreases in crop yields.

The impacts of drought conditions on crop productivity are highly dependent on farming practices, more specifically the use of available irrigation systems. The 2016 Agricultural Census of Canada reported that only 117 farms and approximately 5,434 acres of land within the Essex region have implemented irrigation systems. Meaning that the other farms (approximately 320,000 acres) are completely dependent on natural precipitation to water their crops and are susceptible to drought conditions.

Soil types are also a factor that influence the impacts of drought conditions on agricultural fields. The Essex region consists mainly of clay-based soils, which are able to retain high levels of soil moisture (LIO, 2017). Due to the fine texture of clay, water infiltration in clay is much slower compared to sand-based soils. This means that water drainage from clay soils takes much longer (Brouwer et al., 1985). Despite the water retaining characteristics of the Essex region's soil, the region's farmers are already seeing impacts of drought conditions on their crops (Layson, 2016). This is only expected to increase as drier climates are projected to become more frequent in the future (IPCC, 2013).

Drought conditions can also impact pest and disease infestation of crops. For example, some species within the fungal genus Fusarium, thrive during below-average rainfall conditions and contaminate cereal crops such as corn and wheat (Motha, 2011). Leaf eating insects, such as aphids, are more abundant during drier conditions and have a particular affinity for water-stressed crops (Azeez et al., 2005). Weeds can also interfere during drought conditions by increasing competition for water and nutrients, resulting in considerable decrease in crop yields (Azeez et al., 2005).

While drought conditions have a negative impact on crop yields, it is important to note that soil moisture deficits may provide some benefits to crop productivity as long as they are not too extreme. Low soil moisture has been shown to facilitate rapid downward root growth, accelerate flowering and speed up maturation (Grinnan et al., 2013).

Farmers can find information on how to monitor field soil moisture content on the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) factsheet: Monitoring Soil Moisture to Improve Irrigation Decisions (http://www.omafra.gov.on.ca/english/engineer/facts/11-037.htm).

Impact on Crops

Grains & Legumes

Understanding how soybean, wheat, and corn will respond to increasing temperatures is critical since they represent 68% of the agricultural production in the Essex region (Statistics Canada, 2016a). On a broader scale, grain and legume products provide two-thirds of human caloric intake worldwide (Zhao et al., 2017). Although soybeans are considered legumes and not grains, they have many physiological similarities and are often directly compared to one another. Some of the differences between soybean, wheat, and corn are that their optimal temperatures and range tolerances all differ (Table 2.).

Crop	**Optimal Planting Soil Temperature (°C)**	**Optimal Planting Months and Mean Air Temperature (°C) - Baseline (1976-2005)**	**Optimal Planting Months and Mean Air Temperature (°C) - 2021-2050**	**Optimal Planting Months and Mean Air Temperature (°C) - 2051-2080**	**Optimal Growing Temperature (°C)**
Soybean	10	May (14.4)	April (9.8)	April (11.7)	30
Wheat	5	Oct (11.6)	Oct (13.7) Nov (6.9)	Oct (15.7) Nov (8.7)	21-24
Corn	10	May (14.4)	April (9.8)	April (11.7)	25-33

Table 2. Optimal environmental conditions for growing three major grain and legume crops

Soybean and corn are fairly similar, both being C_3 plants with identical planting temperatures and almost identical optimal growing conditions. C_3 plants do not have to ability to reduce photorespiration (energy waste due to heat) and usually thrive in mildly warm and wet conditions. When C_3 plants are subjected to increased CO_2 in an enclosed setting, studies have shown that these plants can display slightly higher yields (Streck, 2005). However, when considering field conditions such as elevated ozone and reduced soil moisture, research has shown that C_3 crops may not show any change in yield or even decreased yield. In contrast, wheat has a lower planting soil temperature and a lower optimal growing temperature (Table 2).

Grain crops are most vulnerable to unfavourable environmental conditions during early growth, flowering and grain filling stages (Linkemer, 1998). Waterlogged soils can have serious impacts on crop yields if they occur during these times. Drought conditions in the summer growing season are also expected to negatively impact crop yields as yields are often directly proportional to precipitation rates (Mera et al., 2006). Research has found that soil temperature is within 3.5°C of the air temperature 86% of the time on average at a depth of 10 cm or less (Zheng et al., 1993). The amount of snow cover is the main variable that can increase the difference between soil and air temperature.

Soybean

Temperature

Soybean plants have a higher tolerance to heat than corn or wheat which makes them a popular crop in the Essex region and in the rest of Ontario (Zhao et al., 2017). Soybean growth and yield will be reduced if subjected to sub-optimal temperatures during peak growing months (July and August; Hu & Wiatrak, 2012). In most cases, prolonged air temperatures above 30°C will lead to a reduced yield (Ohio AG Net, 2017). Generally, if 10% of the days during July and August are above 30°C, soybean plants will experience heat stress and a reduced yield is expected (Ohio AG Net, 2017). However, if temperatures exceed 39°C for 10% of July and August then soybean pod formation will be severely affected, and the yield will be significantly reduced (Ohio AG Net, 2017).

Since the average July and August temperatures are expected to increase to close to 30°C by 2050, average or mild years may result in unchanged soybean yields depending on precipitation amounts (PCC, 2019). However, above average years with temperatures above 30°C will likely result in reduced soybeans yields. Overly high nighttime temperatures will not severely impact soybean growth because soybeans have higher optimal temperatures to begin with (Ohio AG Net, 2017; Zhao et al., 2017). It is important to note that temperature is not the only factor determining yield and sub-optimal conditions as precipitation, light, soil moisture or air quality can all impact yield (Hu & Wiatrak, 2012).

Growing Season

In Ontario, soybeans are typically sown in mid-May. In southwestern Ontario, it has been found that precipitation in January and April are negatively related to soybean yields (Harris et al., 2016). A study conducted in southern Ontario during the years of 2010-2012 sought to examine the differences in soybean yields between early planting (April 15 - May 5) for longer maturing crops, and normal season planting, and was compared to late season planting. It was found that in exceptional growing years (those with longer growing seasons and had favourable climatic variables), the early planting date was correlated with an increase of approximately 4.5% over the traditional planting date, and 16.8% over the later planting date (Harris et al., 2016). This strategy was highly beneficial to farmers as an earlier planting season came at no increased cost under these conditions; it is important to note however that there are risks associated with earlier planting – if spring thaw brings about floods, farmers may lose their crops and have to replant. These gains in yield were not observed in the following two years however, as less favourable climate conditions resulted in similar yields between early and regular season crop planting times (Harris et al., 2016). The later planting date produced significantly lower yields with losses of 7.6%, and thus will not be recommended (Harris et al., 2016). These increases in yield may be negated, however, if changes in temperature and precipitation are higher than 20% as this can result in crop yields of 2.6% lower than usual. Soybeans are expected to benefit slightly from an increased growing season, with an estimated yield increase of one quarter of the magnitude observed in wheat and corn (Cabas et al., 2009).

Precipitation

Short-term floods of less than two days are unlikely to negatively impact soybean yields. Excess water lasting over four days can delay the plants' growth, while flooding of six days or longer can significantly reduce yields (Coulter et al., 2018). Soybeans can see decreased yields of more than 40% if prolonged flooding conditions occur during early seed filing stages (Steduto et al., 2012). Even larger yield losses can be seen if flooding occurs during late stage reproductive phases (Coulter et al., 2018).

Drought-stressed conditions can prevent soybeans seeds from maturing, which result in seeds at harvest being green in colour (OMAFRA, 2009). This effect is most severe if dry soils occur during July and August, which for the Essex region are the two driest months of the growing season. Additionally, drought conditions can result in soybean yield reductions of 37.5% (Grinnan et al., 2013).

Corn

Temperature

Corn is an integral crop for the Essex region as evident by the nickname of "The Corn Belt". The climate of the Essex region due to the Great Lakes provides suitable growing conditions for seed corn. Above-average nighttime temperatures during the grain fill period can reduce kernel number and weight. Furthermore, increased summer temperatures in July and August were found to be negatively correlated with corn yield (Goldblum, 2009). However, precipitation is an important factor that can alter yields on a year-by-year basis. Zhao et al. (2017) projected that corn will experience the greatest loss in yield per global mean temperature increase. However, another study has reported that corn yields will likely increase in the future due to increased temperatures (Harris et al., 2016). This likely indicates that location and other environmental factors may play a considerable role in corn yields.

Growing Season

Due to the higher ideal temperature and maximum temperature threshold, corn is expected to experience improvements as a result of an extended growing season. The maximum temperature threshold of 45°C also means that corn will remain a viable crop for the near and distant future despite climate related changes for the region (Gornall et al., 2010). It was found that the most significant impact on corn yield will be growing season length, with a 10% increase in growing degree days projected to result in increases in corn yield by 12.2% (Harris et al., 2016).

Precipitation

Young corn plants are particularly vulnerable to flooding conditions and will likely die if submerged in water for more than five days (OMAFRA, 2009). Following the 8-leaf stage, corn can survive flooding for around eight days; however, it will be more vulnerable to disease and experience inhibited root development which will substantially reduce crop yields. Once corn reaches late vegetative growth stages (10-16 leaves) flooding will result in very little yield reductions (OMAFRA, 2009).

Corn requires approximately 500 mm of water during the growing season to produce high yields (OMAFRA, 2009). During drought conditions, corn can see cob weight reductions of up to 34% as well as a 24% increase in seedling death if occurring during germination (Azeez et al., 2005). Furthermore, corn is most susceptible to dry conditions during the tasseling-to-silking stage, which can also result in significant yield reductions if water stressed during this stage (OMAFRA, 2009). In the later stages of vegetative growth, corn may actually benefit from dry conditions as it can facilitate more rapid downward root growth to reach soil moisture.

Wheat

Temperature

Although four types of wheat are grown in Ontario, only Canada Eastern Soft Red Winter wheat is grown in the Essex region (Grain Farmers of Ontario, 2020). The different types of wheat differ by their colour (red or white), hardness (hard or soft) and growing season (winter or spring). Canada Eastern Soft Red Winter wheat is the most compatible with the Essex region's current climate and soil conditions. This type of wheat is mostly used to produce cookies and cereals. Compared to soybean, research suggests that wheat is especially vulnerable to increased temperatures. A higher than optimal temperature during the growing season (> 15°C), decreases the number of days that wheat can photosynthesize which reduces yield (Asseng et al., 2015). An agricultural study found that extremely high temperatures during the growing season (> 34°C), prevented wheat from reaching grain set which resulted in a yield of zero (Asseng et al., 2015). Since research has found a linear relationship between wheat yield and temperature increase, wheat growers in the Essex region should expect a continual yield decline as temperatures increase throughout the 21st century (Asseng et al., 2015).

Growing Season

It has been found that at mid-latitude regions, such as the Essex region, a local increase of 2°C could result in increases of wheat production by nearly 10% (Gornall et al., 2010). Winter wheat crops were found to be similar to corn, and higher yields are projected with an increased growing season. These increased yields are expected to offset the detrimental effects of other climatic variables. (Cabas et al., 2009).

Precipitation

Waterlogging conditions on wheat crops can result in substantial yield reductions when occurring during vegetative growth stages, seeing between 20-50% yield decreases if waterlogged for more than 10 days (Wiersma, 2018). Compared to other crops, such as corn, wheat is much more tolerant of drought conditions. However, wheat is most vulnerable to drought conditions during vegetative and reproductive growth stages with 20% yield reductions occurring if during these times (Daryanto et al., 2016).

Vegetables

Tomatoes

Temperature

The climate of the Essex region currently provides ideal growing conditions for tomatoes, exemplified by Leamington being nicknamed the “Sun Parlour of Canada”. Tomatoes are one crop of particular importance for the Essex region as they provide high economic value for the region (LeBoeuf et al., 2009). Climate variability can significantly alter yields for field tomatoes on a year-by-year basis. Therefore, greenhouses in the Essex region are being increasingly used for tomato farming. Field tomatoes are still viable but in order to achieve ideal tomato development, nighttime temperatures must not exceed 30°C for prolonged periods of time. Additionally, one study found that field tomatoes experienced lower flower numbers and poor fruit set when subjected to daytime or nighttime temperatures below 14°C and above 26°C (Adams et al., 2001). If tomatoes are subjected to daytime or nighttime temperatures above 35°C, then the plant will experience considerable growth reduction (OMAFRA, 2016). Increasing temperatures in the Essex region may result in lower yields if there are periods of extreme heat during the growing season. Mild growing seasons without extreme temperatures could result in unchanged or even increased yields depending on factors related to precipitation. In summary, field tomato yield is highly variable and is difficult to predict based on average air temperature projections alone.

Growing Season

Tomatoes are a very cold and frost-sensitive plant and die when mean outside temperatures fall below 0°C. Tomatoes require a frost-free growing season of around four months in order to reach maximum potential productivity (Kalbarczyk, 2011). Tomatoes are also sensitive to the heat and as a result, longer growing seasons may provide more opportunities for crops to be damaged due to heat stress (Kalbarczyk, 2011). Increases in growing season will have impacts on the phenological phases, developmental stages and agrotechnical dates of the tomato plants in the Essex region.

A study conducted in Poland concluded that the growing season of the tomato plant was extended by a range of 0.6 to 3.5 days over 10 years as a result of accelerated dates of planting (-0.6 days), flowering (-0.7 days), fruit setting (-1.1 days), the beginning of harvesting (-3.5 days), and delay of end of harvesting date (2.1 days; Kalbarczyk, 2011). The largest growing season change in the development of tomatoes was found to be during the fruiting period, from the beginning to the end of harvesting, which was found to increase by 5.6 days over 10 years (Kalbarczyk, 2011). The lengthening of this growing season was not consistent throughout the country; however, the southern parts of the country experienced the largest increases in growing season (Kalbarczyk, 2011). It may be assumed that the Essex region will experience similar benefits to those found in southern Poland as the summer growing temperatures are relatively similar (Kalbarczyk, 2011; PCC, 2019).

The Essex region will face higher temperatures during their summer season especially with temperatures predicted to rise in the future. As such, thermophilic varieties of the tomato plant should be identified in order to both take advantage of rising temperatures, as well as adapt to them (Kalbarczyk, 2011). Furthermore, farmers are cautioned against planting tomatoes too early into the season, as unpredictable spring frosts may occur, causing plants to be damaged (Kalbarczyk, 2011).

Precipitation

Tomatoes are a long-season crop that have very high-water requirements throughout their life cycle (LeBoeuf et al., 2009). The average field tomato requires about 400 mm of water over the growing season (LeBoeuf et al., 2009). However, natural rainfall during this season in Ontario is very irregular, ranging anywhere from 200 mm to 700 mm (LeBoeuf et al., 2009). This means that in many years tomato crops do not receive the sufficient water requirements for optimal growth. The most important water requirement periods for tomatoes are during their critical growth stages which increase their water uptake. These periods are during the flowering, fruit set and fruit sizing stages of development (LeBoeuf et al., 2009). Lack of or irregular water supply during these growth stages can result in fewer flowers per truss, fruit dropping, smaller or cracked fruit, blossom-end rot and reduced fruit set.

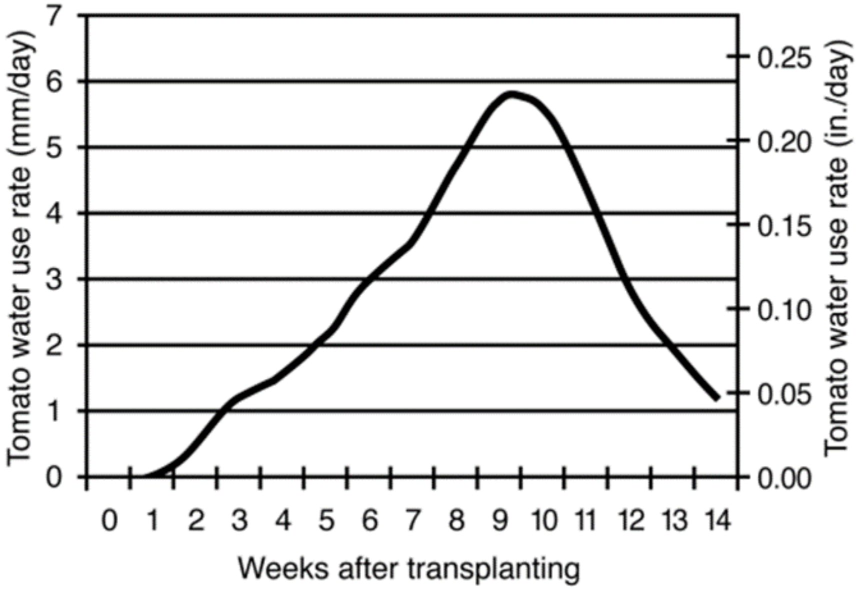


Figure 2. Average daily water use rate for field tomatoes throughout the growing season in Ontario (LeBoeuf et al., 2009).

Figure 2 shows the average daily water use for field tomatoes during the growing season. This indicates that the highest water requirements for tomatoes are during some of the driest months of the growing season, July and August. While the lowest requirements are during the typically wetter spring season.

Irrigation of tomatoes can result in higher and more consistent yields with larger, better quality fruit and less crop damage (LeBoeuf et al., 2009). Studies indicate that tomato yields can increase as high as 81% on multiple different soil types when following a proper irrigation schedule. However, the Essex region relies heavily on natural precipitation for water crops as very few farms use irrigation systems across the region (Statistics Canada, 2016d). This means that the continued dry summer seasons expected for the region may decrease tomato yields on farms reliant on natural precipitation.

Farmers can find information on optimal irrigation schedules for tomatoes and vegetables on the OMAFRA factsheet: Irrigating Vegetable Crops (http://www.omafra.gov.on.ca/english/crops/facts/info_irrigation.htm).

Fruit

Apples, Grapes, Strawberries, and others

Fruit growing is usually restricted to locations where winter temperatures do not fall below -20°C during the winter months (OMAFRA, 2013). Along with having fairly mild winters, the Essex region has one of the longest growing seasons in Ontario which provides suitable growing conditions for many fruits (OMAFRA, 2013). The main fruits grown in the Essex region are apples, grapes, and strawberries (ECFA, 2015). For classification purposes, apples are a tree fruit crop, grapes are a vine crop and strawberries are soft fruits.

Temperature

Apples are perennial tree fruit crops which means they undergo a dormancy period during the winter (Else & Atkinson, 2010). This dormancy period prevents growth until exposure to low temperatures during cold months. The chilling during the winter leads to bud breaking after heat exposure in the spring, which allows for new flowering (Else & Atkinson, 2010). If buds are not broken due to cold temperatures, poor flowering leads to limited pollination and therefore, reduced yields (Else & Atkinson, 2010). To reach the chilling period, most apple tree varieties must be subjected to temperatures below 7°C for at least 500 hours (chill hours). Since winter temperatures in the Essex region are still expected to remain below 7°C for the remainder of the 21st century, apples will likely be able to be grown in the Essex region with unchanged yields.

Grapes are a very lucrative crop which are used for both food and wine production in Ontario. Although grapes require relatively warm growing temperatures, grapes are still subject to heat stress under extreme temperatures. Prolonged temperatures above 40°C have been found to reduce yield in some grape varieties (Greer & Weedon, 2017). Heat stress can cause berry damage, shrinkage, sunburn, reduced rate of ripening among other effects; however, stem and leaf growth typically are unaffected

(Greer & Weedon, 2017). Therefore, it is possible grape yields in the Essex region will be negatively affected in years of extremely warm and dry summers, but overall grape yields should be mostly unaffected.

Strawberries are an economically important berry crop that are in high demand for both use as fresh fruit and in the fruit processing industry. The optimal growing temperature range for strawberries is between 15°C and 27°C. Temperatures above 30°C can cause heat stress and harm the development of strawberry plants. Additionally, research suggests that strawberry production could be affected by increased temperatures due to changes in crop cycle duration (Palencia et al., 2009). Strawberry yields in the Essex region could be reduced under years of extremely high summer temperatures but should be relatively unchanged in the near future based on climate projections (PCC, 2019).

Growing Season

Various fruits require particular growing conditions to ensure proper growth and development. All plants have shown advancements in timing of their phenophases, mainly in spring, which was well correlated to the beginning of the growing season (Chmielewski et al., 2004). Warming temperatures will result in increased growing seasons for all these fruits; however, farmers must be wary of the earlier blossoming of the fruit which could result in damage by late frosts (Chmielewski et al., 2004). Frosts before the beginning of the spring bloom may cause masked injuries; however, this damage is less than if it occurs during the blooming season. Late spring frosts which occur during the blossoming period are very harmful to the blossoms and could result in total crop failure if they take place (Chmielewski et al., 2004).

Grapes are one of the fruits expected to be impacted by this shift in the growing season. A longer growing season due to earlier spring warming and/or later autumn cooling may have the potential to improve vine storage reserve status and cold hardiness (Keller, 2010). These benefits are only expected to be realised if the warming trend does not result in compromised cold acclimation in autumn, cold hardiness in winter, and declamation in spring (Keller, 2010). Recent trials have shown; however, that an increase of 2.2°C during the cold acclimation period resulted in less cold-hardy grapevine buds and canes during the next winter (Keller, 2010).

Precipitation

Excessive soil moisture, as a result of increased precipitation, is one of the leading climate related concerns for fruit tree farmers (OMAFRA, 2020). Flooding conditions in apple orchards can result in soil compaction, root rots, fruit cracking, nutrient deficiencies and tree mortality (OMAFRA, 2020). This hinders tree root development which can reduce yields and increase the trees' vulnerability to tipping over as a result of heavy winds or high crop load. Fortunately, tree roots are the most tolerant to flooded soil conditions during spring, right before bud break.

Lack of soil moisture is also a leading climate concern for fruit tree farmers. Drought conditions on orchards can cause growth reductions, smaller fruit size and weight, reduced tree survival and development and nutrient deficiencies (OMAFRA, 2020). The most critical periods for moisture include, seed setting, blooming, fruit sizing, fruit ripening and tree hardening. When insufficient soil moisture occurs during these critical growth periods, it affects produce yields ultimately reducing produce volume and the average fruit price. For other fruit, such as grapes, drought conditions can also have negative impacts. Lack of water can inhibit vine growth in grapes, reducing the leaf to fruit ratio which decreases the vines capacity to ripen fruit (Fiola, 2011). Suppressed or delayed fruit ripening can negatively affect the quality of the grapes and increase disease susceptibility (Fiola, 2011).

Impact on Phosphorus Transport Pathways

Climate change is influencing both the phosphorus (P) cycling and ecology of Lakes Erie and St Clair, as well as the P loadings from the watersheds. Data collected since the mid-1990s on nutrient loading have shown that the recurrence of harmful algal blooms (HABs) as well as the increase in frequency of these events directly correlate to an increase of dissolved reactive phosphorus (DRP). This has been linked to agricultural non-point sources due to an increase in the application of synthetic fertilizers in this region (Guo et al., 2020; Williams et al., 2018; Wolf et al., 2017). It has been determined that 25 to 75% of the phosphorus in fertilizers is lost from the fields at the time of application, which then enters adjacent waterways (Wurtsbaugh et al., 2019). This nutrient mobilization is influenced by many factors, such as the mechanisms of surface runoff, the intensity of precipitation events and agricultural management practices (Dean et al., 2008).

HABs are composed of cyanobacteria, also known as blue-green algae (e.g. microcystis) that release toxins like microcystin. The impacts to lake ecology are too numerous to cite but it is well understood that warmer, wetter weather is adding stress to an already stressed system and cyanobacteria growth rate is accelerated at higher temperatures. Air temperatures in the region have risen in every season (Maher and Channell, 2021), and with wind speeds projected to decrease, we can expect increased stratification in the lakes, exacerbating the harmful algal blooms (HABs) that have become an annual occurrence in the western basin of Lake Erie as well as the southern shores of Lake St.Clair. The presence of these toxins can make water dangerous for human consumption, recreation and wildlife. Lake Erie HABs also effect local tourism, recreation activities, and sport and commercial fisheries, directly impacting the economy in the area. In the future, under business as usual scenarios, we can expect blooms to intensify earlier in the summer, with a longer bloom window (up to two additional weeks), in Lake Erie and Lake St Clair.

The interactions between climate variables, crop growth, P availability and crop uptake, surface runoff and subsurface drainage are complex and primarily driven by the projected change in precipitation patterns. To predict the future response of watersheds to P loading, researchers use hydrological models, such as SWAT (Soil and Water Assessment Tool) or EPIC (Environmental Policy Integrated Climate) with inputs that include a range of downscaled global and regional climate models. These hydrological models simulate DRP loss from surface runoff and subsurface drainage under future climate scenarios. EPIC can also be used to simulate physiological crop growth and P uptake by crops. Table 3 summarizes climate projections and possible impacts and vulnerabilities of phosphorus pathways.

Several studies suggest a warming climate may counteract the increase average amount of rain throughout the year leading to lower P loadings across Great Lakes watersheds (Wang et al, 2021; Kalcic et al. 2019). However, both studies used averages in precipitation across months and seasons and do not consider the increase frequency in extreme events. Projections for the region suggest that total precipitation will slightly increase but large changes are expected in the extremes, with summer rains becoming concentrated in fewer events of higher intensity, interspersed with prolonged dry periods. It is generally understood that these extreme precipitation events will lead to pulse loading. It situations where summer drought was followed by an intense rainfall, Sol Lisboa et al. (2020) found significant transfer of P and sediment from the landscape to the tributaries.

Actions for the managing phosphorus from all sources are being developed through a regional Phosphorus Management Plan currently being advanced by ERCA. However, it is clear that additional funding for nutrient management and phosphorus reduction best management practices will be required.

PROJECTIONS	IMPACTS
Increased temperature all year round. Average, maximum, and minimum temperatures are expected to increase Average increases between 1.69 for minimum temperature and 1.60 for maximum temperature. **Increased number of days over 30 degrees in the summer**.	• Increased soil desiccation cracking and shrinkage, leading to increased susceptibility to intense precipitation and runoff due to increased permeability • Drought leading to hardening of soil and decreased infiltration for groundwater recharge/discharge • Increased temperatures leading to greater plant potential evapotranspiration (PET) or evapotranspiration (ET) leading to lower DRP reduction in surface runoff and subsurface drainage. • Increased soil temperature, leading to increased flow rate transfer between labile and active mineral P pools, leading to increased crop P uptake • Non-growing season decline in evapotranspiration, resulting in increases in surface runoff and subsurface drainage water discharge
Increased precipitation all year round. The largest increases in precipitation are expected during the spring and winter months, specifically December, January, February, March, and April. Precipitation in March is expected to increase by as much as 13% (8 mm) by 2050. Fall and summer months are expected to see small increases in precipitation.	• Leading to changes in hydro-period and increased runoff, decreased infiltration • Leading to changes in nutrient transport process; groundwater – picks up current & legacy nutrients • Leading to changes in runoff timing
Timing, intensity, frequency and duration of precipitation events. In general are projected to become more intense and extreme. Precipitation will fall at a faster rate; shorter storms will have an increasingly high intensity; shorter return periods of heavy storms	• Increased intense rainfall events leading to increased runoff • Changes in flood frequency • Change in nutrient transport process; groundwater – picks up current & legacy nutrients • Changed hydrological regime "flashy" flows • Increased flow in watercourses leading to increased erosion and subsequent sediment & particulate P deposition

PROJECTIONS	IMPACTS
Frost and ice days are expected to decrease considerably in the future. In the recent past (1976-2005), the Essex Region experienced 117 frost days and 45 ice days. By 2050, the number of frost days is expected to decrease by 22% (25 days) and the number of ice days is expected to decrease by 35% (29 days).	• Changes in snowpack/ice duration
Wind: Annual average wind speed projections varied from a decrease of 4% to an increase of 1%	• Decreased wind speeds result in lower PET and ET thereby eventually increased surface runoff and subsurface drainage • Leading to less wind-transported sediment and deposition
Short wave radiation modeling varies from a decrease of 3% to an increase of 2%	• Potentially increases PET and ET leading to lower surface runoff and subsurface drainage.
Atmospheric carbon dioxide is projected to increase	• Leading to increased P uptake by crops and vegetation • May lead to slight decrease in PET and ET due to reduction of stomatal conductance leading to increased surface runoff and subsurface drainage; leading to DRP loss in surface runoff but DRP loss in subsurface drainage decreased by 11%.
Relative humidity is likely to decrease up to 5% in the future	• May lead to minimal increase in PET and ET leading to lower surface runoff, subsurface drainage, and DRP loss.

Table 3. Impacts of Climate Change on Phosphorus Transport Pathways. Climate data was accessed from Climate Atlas and Wang et al. 2021; impacts summarized from Wang et al. 2021

Mitigation & Adaptation Recommendations

The Essex region is projected to experience increased temperatures as well as increased annual precipitation within the next century (PCC, 2019). These changes will result in longer growing season lengths, increased heat stress and increased flooding and drought incidents (PCC, 2019). Longer growing seasons can result in more opportunities to increase crop productivity and yield. However, accompanying hotter temperatures and flooding incidents will have serious impacts on crops including limiting their growth and development, reducing yields, and making it difficult for crops to grow in their optimal environments (Turral et al., 2011). It is clear the agricultural sector will need to improve and adapt current farming practices to be better prepared for climate change and its related environmental effects in the future (Smit & Skinner, 2002).

Chapter 2.

Chapter 3.

Growing Season

As the growing season lengthens, alternate seeding and planting schedules may need to be introduced within the Essex region. If temperatures rise high enough to extend the length of the growing season substantially, farmers could potentially plant cultivars earlier in the year which possess faster development rates, allowing them to have two harvests instead of one (Brassard & Singh, 2007). It is recommended that the seeding and harvesting of crops be staggered through the use of planting a variety of different crops requiring a range of growing conditions (Brassard & Singh, 2007). This is advised to increase the adaptive capacity of the region as crops at different stages will experience different levels of vulnerability to various climate drivers due to differing phenology and cultivar use (Harris et al., 2016).

Due to the changes in growing season, it is recommended that agricultural research be completed into different crops that are suited to a changing climate (Morand et al., 2017). In addition, it is advised that farmers begin to invest in field trails for new climate resilient crop rotations most suitable for the Essex region. For example, in the Peel region, a municipality within the Greater Toronto Area; buckwheat, rye, quinoa, and switchgrass underwent field trials (Harris et al., 2016). These crops may be worth investigating as the Essex and Peel region are in located close to each other and share similar climates. Climate change will bring about warmer, longer growing seasons, and in order to reap the full potential of future yields, farmers may have to adopt different cultivars which are better suited to the new conditions (Morand et al., 2017). However, in order to achieve this, there is a continued need for provincial support for both public, as well as private research and development programs focused on new crop hybrids which are better adapted to climate change (Morand et al., 2017); (https://cban.ca/gmos/products/on-the-market/).

Irrigation Strategies

As the frequency and intensity of heat waves are expected to increase under climate change, farmers in the Essex region can mitigate the exacerbating impacts of heat stress and droughts by better managing irrigation (OMAFRA, 2017). Drought conditions in agricultural fields are highly dependent on the availability of irrigation systems. As previously mentioned, 117 of the 1630 farms (5,434 out of 328,174 acres) within the Essex region report using irrigation systems to water their crops, many of which were discussed in Chapter 4 (Statistics Canada, 2016d). This means that most crops across the region are solely reliant on natural precipitation for their water requirements. Large-scale irrigation systems may require a high initial cost but there are many benefits to using irrigation systems including; being able to control water quantity during natural water shortages to ensure the specific water requirements at optimal growth stages, improving the overall quality of the crops and increasing crop yields (USEPA, 2015).

It is becoming increasingly important to provide crops with water using irrigation systems during intensely hot days to mitigate the impacts of heat stress and drought. Even a few hours of intense heat can permanently damage crops by scorching their leaves and stems which considerably reduces their crop productivity and yield (Raza et al., 2019). This solution requires the farmers to use their best judgement using the resources they have (such as listening to local weather forecasts) and providing additional irrigation during times when heat intensity is at its peak (Pitesky et al., 2014). Although this method is currently practiced amongst some farmers, it may not be a feasible method in the future when intensely hot days become more common (Turral et al., 2011). More long-term water conservation strategies can include utilizing new water-efficient technologies to optimize the use of irrigation water, track irrigation practices and monitor on-farm water supply (Pitesky et al., 2014).

The two most common types of irrigation systems in Ontario are drip irrigation and overhead irrigation (LeBoeuf et al., 2009). Overhead irrigation works by dispersing water in the area above or surrounding the crops foliage, thus water travels through the canopy of the plant and into the root zone of the crops (Lieth & Oki, 2019). Compared to other irrigation methods, overhead systems are the easiest to implement and the least expensive distribution methods (Berle & Westerfield, 2019). However, they are also the most wasteful as a lot of water is lost to evaporation and runoff, making operating costs much higher. Compared to other irrigation systems, overhead systems use much more water which could increase runoff volumes from agricultural fields and increase nutrient leaching. Drip irrigation involves a network of pipes that disperses water either near or within the crops root zone (Shock, 2013). This system applies water in a slower and more efficient manner allowing the farmer to save water and the crops to receive the most optimal amounts of water. It also has many environmental benefits, most importantly being that runoff volumes are significantly reduced as the controlled system applies water as needed for crop use.

In some cases, farmers who invest in such technologies can benefit by optimizing their irrigation water and developing economic resilience against climate change. However, it is important to consider that certain irrigation systems, such as drip irrigation, require high up-front capital crops to the farmer at approximately $1,500 per acre (Shock, 2013; Carter, 2016), meaning that implementation of these systems may only be feasible for high value crops.

Conservation Tillage

Field management practices such as conservation tillage play a very important role when determining field vulnerability to erosion and nutrient loss. Conservation tillage practices include no tillage, mulch tillage, intercropping and many others. These practices can increase resilience against climate change as it decreases soil disturbance, and allows for the accumulation of organic matter, water and essential soil microbes to maintain and increase crop yields (OMAFRA, 2017). In addition, by incorporating crop residue into the soil, these practices conserve the fields' organic matter, slow soil deterioration, improve drainage, increase water and nutrient carrying capacity and improve conditions for soil organisms to thrive (Swanson & Kelkar, 2006). Furthermore, conservation tillage is also a proven practice used to maintain soil moisture during drier conditions (Crawford & MacNair, 2012). However, successful conservation tillage practices are partially dependent on effective use of alternative field management strategies. For example, farmers must ensure fields using conservation tillage have good soil drainage and water infiltration (OMAFRA, 2017). In addition, farmers must incorporate residue management to maintain some soil cover and effective weed control strategies without the use of tillage (this may involve using more pesticides) (OMAFRA, 2017).

It is promising to observe the total land acreage in the Essex region currently employing conservation tillage practices shown in Figure 3. Within the region, the figure indicates that the most common tillage method in the region are no-till practices. For those farms not using conservation tillage strategies, shifting to new practices will likely need ongoing monitoring and multiple tests to optimize its use and improve crop productivity. Furthermore, farmers must have access to credible, easy to understand, scientific information which highlights the best agricultural practices to save money and improve crop productivity. Lastly, switching to new methods can pose a financial risk, therefore funding provided by external stakeholders can encourage the purchase of new or modified equipment necessary to employ climate resilient techniques within the agricultural sector (OMAFRA, 2017).

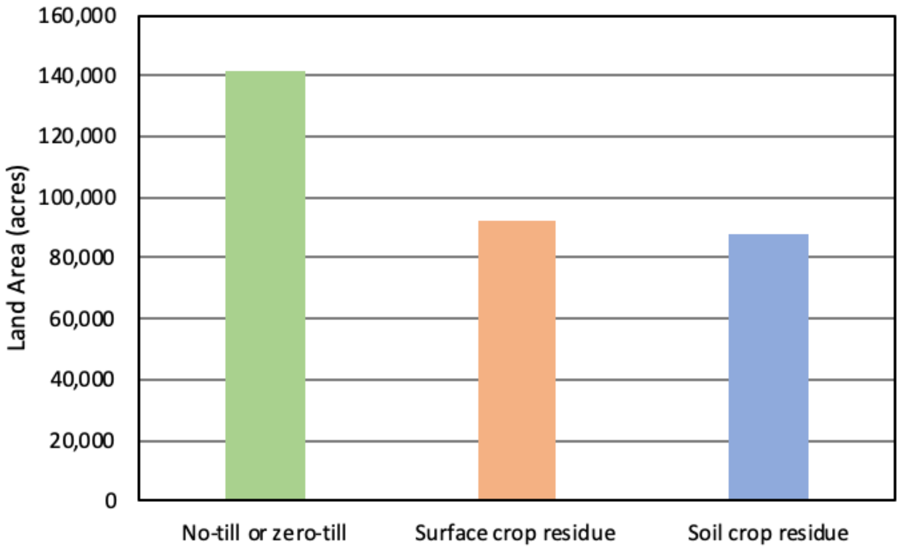


Figure 3. Land acreage of farms in Essex region using conservative tillage practices. (Census of Agriculture 2016, Table 32-10-0408-01).

Controlled Tile Drainage

Tile drainage presents one solution to control the current and expected flooding of agriculture fields in the Essex region. These systems remove excess water from the fields' soil to decrease the impacts of flooding and improve crop production (USEPA, 2015). Conventional or uncontrolled tile drainage works through a network of perforated tubes placed a few feet below the soils surface. When the water table rises above the tile system, water drains into the tubes and out into a drainage outlet, most commonly a ditch. Controlled tile drainage involves the same tubing network as uncontrolled drainage however has the addition of flow control structures that are installed right before the drainage outlet (Figure 4).

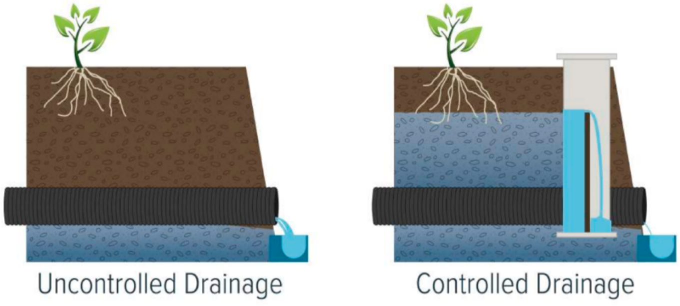


Figure 4. Cross-sectional view of uncontrolled tile drainage systems compared to controlled tile drainage systems. (OSCIA, 2016)

This simple addition allows for the adjustment of field water levels throughout the year. With control systems typically being open during the wet spring season, allowing for continued drainage and closed during the dry summer season, allowing the water table to rise for crop use. There are many benefits to controlled drainage systems compared to uncontrolled systems (OSCIA, 2016). These benefits include:

- Increase crop yields by up to 25%
- Increased drought resistance through reduced water loss and soil nutrients
- Annual yield benefits between $48 - $78/ha
- Reduced nutrient loss of ammonium by 57%, nitrate by 65% and phosphorous by 63%
- Local waterway nitrogen load reductions of 50-100%

Cost of implementing such systems depends on the size of the field and whether or not a drainage network is already in place. If tile drainage is already installed, cost of the control structure is relatively small ranging from $500 - $3000 per structure (OSCIA, 2016). The Ontario Soil and Crop Improvement Association (OSCIA) has an online tool that displays the crop yield benefits of implementing controlled tile drainage on farms across Ontario (https://demo.gatewaygeomatics.com/ctd/).

While there are many benefits to controlled tile drainage systems, it is important to note that the free-flowing drains during the wet season still allow for nutrient loss (King et al., 2015). The Essex region is currently practicing controlled drainage on a few farms however, the implementation cost is quite high due to the need to reconfigure existing tile drains. Nonetheless, this practice remains a promising water management strategy and it is recommended that ERCA continues to explore this practice as a viable option.

Pest Management

As the climate changes, farmers will need to adapt their management practice to deal with new or increased pests and diseases. It is known that intense heat, drought and flooding conditions result in stressed crops which reduces their optimal productivity and makes them more vulnerable to some common agricultural pests and diseases (OMAFRA, 2017). For example, aphids and some weeds thrive in drought conditions, limiting the growth of crops in the process (Raza et al., 2019). Farmers can incorporate a variety of integrated pest management (IPM) strategies to deal with their specific pest and disease concerns by choosing and applying the appropriate insecticides, herbicides and fungicides at the right time and in the proper quantities (OMAFRA, 2017). IPM strategies differ from traditional pest management strategies as IPM considers minimizing risks to human health and the environment. This can be accomplished by attempting to remove only the target organism while minimizing impacts to the surrounding ecosystem and non-target organisms (OMAFRA, 2017).

OMAFRA has IPM strategies for a variety of crops including apples, grapes, tomatoes, corn, wheat and soybeans. One pest of concern for greenhouse tomatoes is the tomato pinworm (TPW) which attacks both the leaves and fruit of the crop (Ferguson & Shipp, 2009). For this pest, the OMAFRA recommends monitoring the population using pheromones and light traps as well as sanitizing or destroying any infested fruit or leaf to minimize transfer to other plants.

Figure 5 shows the total land acreage in the Essex region using pest and disease management inputs. Herbicides are the most common pest management strategy, indicating that farmers in the region are most concerned with plant pest species. It also indicates that of the 328,000 acres of land used for crops in the Essex region, most of that land is employing pest management practices.

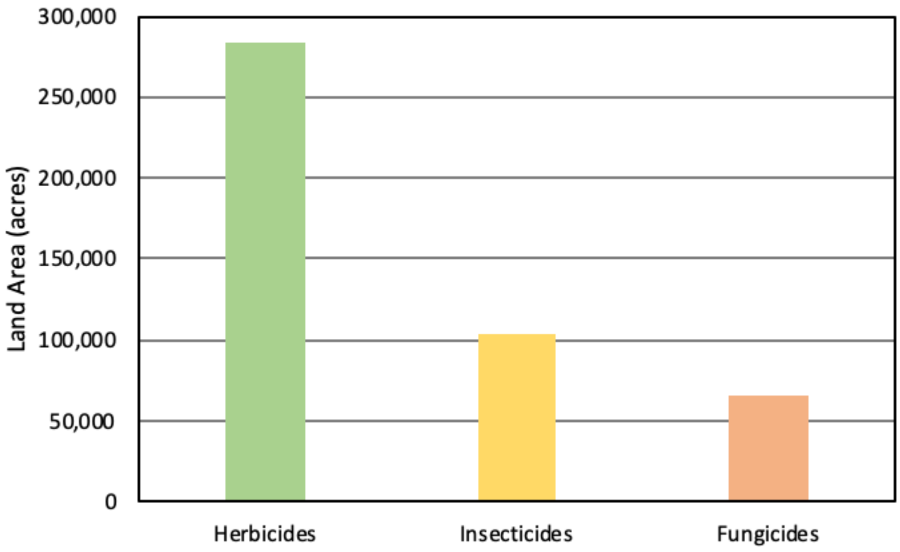


Figure 5. Land acreage of farms in Essex region using pest and disease management inputs. (Census of Agriculture 2016, Table 32-10-0409-01).

GMOs

Developing new crop varieties using cross breeding techniques as well as genetically modified organisms (GMOs) are widely used in the agricultural sector. These new crop varieties can be developed to improve resistance to heat, drought, flooding, pests and other variables to serve as an effective climate adaptive strategy. In Canada, corn, canola, soy, white sugar beet and a few others have been approved for growth; almost all these GMOs are herbicide tolerant (CBAN, 2015). As technology continues to advance, it has become more promising to use a crop's genetic resources as an adaptation strategy against a changing climate (Smit & Skinner, 2002).

Tolerance to temperatures, drought and flooding is a complex trait controlled by multiple genes (Petsky et al., 2014; Reynoso et al., 2019). In short, it is difficult to develop heat-tolerant or flood-tolerant crop cultivars due to limited knowledge and availability of genes. Advances are being made and it is possible that commercially viable climate tolerant crops can be available by 2030 (Petsky et al., 2014). For example, new research from 2019 suggests the only major food crop able to resist flooding is rice. However, this study also found a wild tomato shared similar genes that were activated in response to flooding that could potentially be isolated and implemented into commercially grown tomatoes in the future (Reynoso et al., 2019).

Although these advances are promising, the implementation of new crop varieties will likely require a broad involvement of the agricultural sector and its relevant stakeholders. Farmers must be willing to overcome any stigmas surrounding GMOs as there is a widespread misconception GMOs are not good for human health. This also applies to consumers. If consumers continue to actively avoid GMO products, then farmers would be even more reluctant to make the switch to GMO crops. Furthermore, these technological advancements are highly dependent on both private and public research facilities and their willingness to sell their products for a reasonable price that farmers can afford (Petsky et al., 2014).

Agricultural GHG Emissions

Globally, the agriculture sector makes up 11% of total greenhouse gas (GHG) emissions (C2ES, 2019). Within Canada, agricultural GHG emissions makeup 8.4% of the total, at approximately 60 metric tons of carbon dioxide equivalent (ECCC, 2019). While this is only a small portion of total emissions, the agriculture industry has the potential to remove carbon dioxide from the atmosphere making it a viable option for carbon sequestration.

Agriculture and its practices emit all three major GHGs: carbon dioxide (CO_2), methane (CH_4) and nitrous oxides (N_2O; AAFC, 2020). Soil has the potential to store a significant amount of CO_2 in the form of humus, or organic matter, with the amount of carbon stored being dependent on the farm's management practices. Soil carbon increases when it receives plant litter and decreases (i.e., emits CO_2) when plant matter decays (AAFC, 2020). It is the ratio between these two processes that result in either a carbon sink or carbon source and thus the sequestration potential of the soil. A carbon sink occurs when the carbon inputs are higher than the losses from decomposition. When the opposite occurs, the soil becomes a carbon source and emits CO_2 (AAFC, 2020). Land management practices have the ability to increase soil carbon sequestration. Some practices include; conservation or reduced tillage, crop residue management, creating shelterbelts with trees and shrubs, restoring degraded land, crop residue management and wetland restorations (AAFC, 2020). Not only do these practices increase carbon sequestration, but they also improve soil productivity, improve water quality by reducing runoff and improve farmers' profits (AAFC, 2020).

In Canada, farmers manage approximately 68 million hectares of land and in the past two decades have made considered steps to improve soil management practices (AAFC, 2020). Previous farming practices resulted in soils being a carbon source as cultivation accelerated plant decay and tillage meant less carbon was returned to the soil (AAFC, 2020). Since 2000, Canadian agricultural soils have been sequestering more carbon than they are emitting and it is expected that soil sequestration will continue until at least 2040 if these management practices are upheld (AAFC, 2020). However, there are regional differences across Canada in the amount of soil organic carbon (SOC) sequestration. Since the 1980's farmland in the prairie provinces (Alberta, Saskatchewan and Manitoba) have become a significant sink for CO_2 due to the change from annual to perennial cropping (Smukler, 2019). This practice increases the amount of crop residue incorporated into the soil which improves the build-up of SOC and improves soil health. In contrast, Central (Ontario and Quebec) and Atlantic Canada have seen a steady decline in the amount of SOC due to the conversion from perennial to annual cropping (Smukler, 2019). Annual cropping causes much more soil disturbance, requires more intensive tillage practices and produces less crop residue, all of which decrease SOC. While annual crops, such as corn, make up an important part of the agriculture sector, these differences emphasize the need for stringent management practices in order to improve agricultural carbon sequestration.

Human-impacted landscapes are the most challenging to characterize when it comes to carbon sequestration potential since human activities alter both the aboveground and belowground environment, yet they are the most critical to address and restoration success depends upon improving both ecosystems in tandem. It is recommended that ERCA work with academic research partners to quantify and interrogate key uncertainties associated with carbon sequestration relationships between aboveground vegetation, and belowground soil and roots. These studies will improve translation of the scientific understanding of carbon resilience mitigation options and science needs in clay-based soils in southwestern Ontario. It is critical assess baseline carbon stocks along human impact gradients to inform regional management actions, and set forth a robust framework for prioritization of actions given uncertainties and opportunities.

Cumulative Development Impacts & Subwatershed Planning

Local agriculture provides multiple benefits to the region including significant economic activity and ecosystem services, including carbon storage. Ensuring agricultural businesses are viable into the future is critical to protecting these services (Metro Vancouver, 2021). In this region, farmers are challenged with competing interests for land with extensive subdivision development, as well as from the greenhouse sector, which has expanded significantly in the Kingsville-Leamington area over the last 10 years. These developments have larger ghg emission footprints than field agriculture, without the benefit of carbon sequestration and other ecosystem services. While undertaking subwatershed planning and quantifying potential environmental impacts of new developments, greenhouse gas and carbon sequestration should become part of these assessments. Futhermore, determining the cumulative impacts of multiple development activities on the long-term viability of field agriculture production in the region should be prioritized.

Community Outreach

Successfully adapting to adverse climate and environmental changes due to climate change will require the cooperation and support from several stakeholders connected to the agricultural sector. Farmers will need to understand how climate change will impact their businesses and more importantly be willing to implement appropriate adaptation strategies (Fraser Basin Council, 2019). In addition, regional governments must be supportive and provide financial support which offer the best opportunities to the agriculture sector to improve resilience against climate change. Governments can also implement policies for large industries with high carbon footprints so they can gradually reduce their greenhouse gas emissions (Fraser Basin Council, 2019). Communities in the Essex region can also work together towards a low carbon economy and the development of sustainable resource plans to lower both carbon and resource footprints. For example, a sustainable long-term water usage plan in the region can reduce pressure for water resources required for the agriculture sector (Climate Action Initiative, 2016). These efforts are meaningful as mitigation will reduce the severity of climate change and is an important adaptation strategy.

An example of such an effort can include farmers communicating their climate resilient practices to the community and the market. It is also consumers' and retailers' responsibility to be educated and support crops, technologies, and practices that are best suited for resilience against climate change (Fraser Basin Council 2019; Climate Action Initiative, 2016). This is important because farmers should not be financially hampered for following recommendations to adapt to the changing climate. Lastly, new communication protocols must be established within the Essex community to reduce the impact of extreme weather events attributed to climate change. This can be accomplished by training additional human resources and developing policies to recognize and support additional adaptive capacity against emergency extreme climate events which can devastate crops and the agricultural industry (Fraser Basin Council, 2019).

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Appendices

Summary of Engagement Activities

Essex Soil and Crop Improvement Association (ESCIA) Board Meeting, June 23, 2021

1. Participants were presented with the summary of impacts as identified in this report and were asked if they felt it was this an accurate summary of potential future impacts of climate change to agriculture in the Essex Region.'

Most selected 'Yes, very accurate and we're already seeing these impacts'; several participants selected 'Unsure'. This answer was qualified by one participant who noted that he didn't feel he had the expertise to answer the more technical questions about CO2 impacts on crop growth.

2. Participants were asked which climate impacts they were most concerned about in the future.

Most participants were concerned about the future impacts of flooding on their crops. Several participants were concerned about future droughts. Two participants were most concerned about the future impacts of extreme weather other than flooding & drought (high winds, early frost etc.) on their crops. Two participants were concerned with the cumulative impacts of land development on ag land in the region. One participant was concerned about increased weed growth.

3. Participants were asked what 'climate' actions they had already undertaken or will consider in the future?

All participants noted that they have, or would, plant cover crops. Four participants noted that they undertake conservation tillage / no till in their farming practices. Three participants noted that they would install more tile drains in the future. Two participants noted that they would be re-thinking their crop selection in the future.

4. Participants were asked what the biggest barriers were to undertaking additional adaptation actions.

All participants were concerned about the upfront cost of undertaking adaptation actions. Many participants were also concerned about the lack of knowledge or expertise in the region. One participant noted that the unsecured land tenure was a barrier; one participant was concerned about reduced yields; and one participant was concerned about the effectiveness of these actions or uncertain about future climate projections.

Crops & Conservation Webinar, March 30, 2021

Crops and Conservation

Climate Change Impacts and Solutions in Agriculture

Tuesday, March 30, 11:00 a.m.

Panellists include: Claire Sanders (ERCA), Brent Preston (EFAO), Dr. Catherine Febria (UWindsor), and Dr. Ray Desjardins (AAFC, retired)

This project is funded by the Ontario Ministry of Agriculture, Food and Rural Affairs

Essex Region Conservation

the place for life

This webinar was the last in a series of five webinars that was undertaken by Conservation Authority partners in southwestern Ontario. Participants of this webinar were presented with a summary of impacts as identified in this report and were asked if they felt it was this an accurate summary of potential future impacts of climate change to agriculture in the Essex Region.

Panelists included Dr. Ray Desjardins, a retired scientist from Agriculture and Agri-food Canada, who presented his research on the changes in atmospheric concentrations of greenhouse gases and potential pathways to reduce the impact of the agriculture sector on climate change. Dr. Catherine Febria is a researcher at the University of Windsor. She uses science to accelerate the science and practice of soil conservation and freshwater restoration in agriculturally-impacted watersheds of the Great Lakes Basin. Finally, Brent Preston, President of the Ecological Farmers Association of Ontario, presented an overview of the work of Farmers for Climate Solutions, a new national coalition of farm groups that is advocating for government support for climate-friendly agriculture.

Healthy Headwaters Lab - Farmer Advisory Board Meeting, November 24, 2020

The Farmer Advisory Board (FAB) assesses and advises on current and potential work being done by the Healthy Headwaters Lab and its partners on the intersection of agriculture and freshwater in Southern Ontario. The FAB is made up of 6-10 representatives of the agricultural community who have an interest in locally applicable sustainable agricultural practices. Members represent a range of farming perspectives, including the greenhouse sector and indigenous rights holders.

AGENDA		
7:00pm	Call to Order – Public Symposium	Catherine Febria
7:05	Introduction of HHL and FAB	Catherine
	HHL Projects:	
7:15	Carbon Complexity and Farm Practices	Lauren Weller
7:25	Undergraduate projects overview	Catherine
	Partner Projects:	
7:30	ERCA Climate Change activities	Claire Sanders
7:35	ERCA Phosphorus management activities	Katie Stammler
7:40	Plant-Microbe Relationships for Better Soil: Function of Root Derived Products	Cameron Proctor
7:45	'When the water turns green' - algal blooms in the Thames River	Mike McKay
7:50	Masks demystified, why masks for all with physical distancing work together to reduce COVID-19	Ken Drouillard
7:55	Nature Conservancy of Canada: Essex Forests and Wetlands Natural Area	Karen Alexander
8:00	Adjourn Public Symposium	Catherine
8-8:15pm	Optional break-out discussion rooms	
Group A	HHL project discussion	
Group B	ERCA Climate Change/P management discussion	
Group C	Partner project discussion	
8:15pm	Call to Order – Closed Board Session	Catherine Febria
8:20	Feedback on Public Symposium from FAB	Jess Ives
8:25	P Management Task Force for ERCA (briefing item 1)	Jess
8:35	Strategic direction of FAB (briefing item 2)	Jess
8:50	Concerns/ideas for research from the board members	Jess
9:00	Adjourn	Catherine