Nuffield Canada
AGRICULTURAL SCHOLARSHIPS

Keeping Vines in the Ground and Wine on the Shelf: Safeguarding the Future of Ontario Viticulture with Education and Training

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NUFFIELD CANADA

Nuffield Canada Agricultural Scholarships

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3. Achieve personal development through travel and study
4. Deliver long-term benefits to Canadian farmers and growers, and to the industry as a whole

Applications are due annually by June 30th

SCHOLAR PROFILE

I live in the tender fruit and grape growing region of Niagara in southern Ontario with my wife, Rachel, son, Huxley, and daughter, Florence, both of whom were born within the two-year period of my Nuffield Scholarship travels. I was raised in the Ottawa Valley with no notion that wine grapes could be grown in Canada, but where a few adventurous souls are currently trying their hand at viticulture and winemaking.

The obsessive, sometimes thankless, drive to grow a plant that by nature belongs to a more moderate climate explains in part how I ended up participating in a Nuffield Scholarship.

Born in British Columbia and raised in the Ottawa Valley, I studied the Humanities in Halifax before moving to Europe where I encountered wine in a real way for the first time, picking grapes to fund my ongoing travels and starting to develop my palate by tasting great local wines at every opportunity. On my return to Canada I enrolled in the Winery and Viticulture Technician program at Niagara College in Niagara-on-the-Lake, Ontario, and enhanced my education and palate through the Wine and Spirits Education Trust and the Court of Master Sommeliers courses.

Upon graduation I worked in a variety of vineyards and wineries in Canada, Australia and New Zealand and travelled to global wine regions whenever possible to taste and try to understand the nuances of different growing and production techniques. But I always returned home to Ontario. The potential to make great wines in my home province had really only been realized a generation before mine, but it was clear that the industry had made great strides in becoming a fine wine region in a very short period of time and I was excited to forge a career in it. I settled into full-time work at the Niagara College Teaching Winery, eventually occupying roles as vineyard, hop yard and orchard manager, head winemaker, and instructor. Outside of my work at the College, I teach into the Canadian Association of Professional Sommeliers program and am co-owner and cider maker at Garage d'Or Ciders, a small-batch craft cider production company.

The central role that Niagara College plays in the Ontario grape and wine industry and my personal role training students and helping to match student interns and graduates of our programs with employers in the industry, led me to think critically about the state of this industry and to consider broadly what it might look like in the future. My goal in pursuing a Nuffield Scholarship was to consider the state of this local industry within the context of global viticulture and wine production, and to consider in detail how my everyday efforts to educate the next generation of grape growers and winemakers could be improved. I got much more out of this experience personally and professionally than I ever could have imagined.

ACKNOWLEDGMENTS

I need to thank the Nuffield Canada selection committee for taking a chance on the field of viticulture.

I want to thank Steve Gill and all of my other supervisors and colleagues at Niagara College for providing the time and support that allowed me to embark on these travels for weeks at a time.

I need to thank my wine department colleagues and all of the Winery and Viticulture Technician Program and Wine Business Management program students from the class of 2018 for acting as a sounding board to my rambling about viticulture education and all of the opportunities to bounce ideas off of them.

I want to thank all of the Nuffield Canada Scholars and Directors including Becky Parker, Blake Vince, Karen Daynard, Shannon McArton, Kelvin Meadows and so many other bright, inspiring people who helped me along the way with connections, direction and sound advice.

Thank you to all of the grape growers, winemakers, academics and educators who opened their doors and gave me their time, knowledge and insights, often alongside a glass of spectacular wine.

Finally – especially - I'll be forever grateful to my wife, Rachel, for her endless patience, support, love and companionship throughout these travels and through the sometimes fraught research and report writing process. I truly could not have done it without you.

SPONSORSHIP

My Nuffield Scholarship is sponsored by: Nuffield Canada Alumni.

I am indebted forever to these fine, generous, Canadian farmers.

EXECUTIVE SUMMARY

The Ontario wine industry has seen persistent, positive growth in the last five decades when considering metrics such as acres of planted vines, number of winery licenses registered and domestic and export sales. Nonetheless a variety of challenges face Ontario's grape growers and winemakers including environmental and climatic pressures, planting stock pathogens, land use and pricing issues, worker availability and high labour costs. Ontario producers are operating in an increasingly competitive global market, and to keep pace with the largest wine producing players in Europe, the Americas and Australasia they will have to address these challenges head on. It is my belief that domestic education and training programs play a key role in ensuring the viability of our future industry by producing graduates with essential skills that are highly relevant to the particularities of grape and wine production in Ontario.

Grape and wine quality are driven by access to resources, technology, knowledge and human capital in the form of skilled labour. Hypothesizing that solutions to many of the challenges facing the Ontario grape and wine industry are technical in nature, a core question that I set out to answer was: what knowledge and skills would be most relevant to grape growing in the 21st century? My Nuffield Scholarship allowed me to explore a variety of viticulture training programs located in wine growing regions in France, Italy, Germany, the United States, South Africa, and more. I spent time with researchers, faculty and students to try to understand what viticulture knowledge and skills they thought were most important in the present day, and to find out what topics these experts thought would be most important in the future.

This report identifies critical knowledge clusters and strategies for addressing challenges to Ontario viticulture. These can be studied, taught or implemented at academic and applied agriculture or viticulture training institutions in Canada. This information can be transferred to industry stakeholders including primary growers through part-time courses, workshops or online offerings to help guide their management decisions and business planning.

These topics include specific technological innovations as a response to climate and environmental threats, and vine breeding and nursery systems to help protect the future of the industry. They also include farming techniques which are appropriate to "sustainable" production in various ways and the use of mechanization, precision viticulture technology and autonomous machines and robotics to achieve high productivity with potentially low input costs. Strategies to attract and retain skilled workers in the Ontario grape and wine industry are also addressed. I conclude by making a series of recommendations based on my research findings that apply to Canadian institutions of higher education and to the grape and industry as a whole. These address curriculum priorities, resource allocation and institutional and industry partnership and collaboration models in specific ways.

DISCLAIMER

This report has been prepared in good faith but is not intended to be a scientific study or an academic paper. It is a collection of my current thoughts and findings on discussions, research and visits undertaken during my Nuffield Farming Scholarship.

It illustrates my thought process and my quest for improvements to my knowledge base. It is not a manual with step-by-step instructions to implement procedures.

Neither The Nuffield Farming Scholarships Trust, nor my sponsor, nor any other sponsoring body guarantees or warrants the accuracy, reliability, completeness or currency of the information in this publication nor its usefulness in achieving any purpose.

Readers are responsible for assessing the relevance and accuracy of the content of this publication.

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1.0 INTRODUCTION

1.1 Global Grape and Wine Industry Overview

Products made from the fermented juice of the fruit of a small group of grapevine species have come to dominate the alcoholic beverage market in many countries around the world including Canada, surpassed only by beer in terms of total consumption volume. Global consumption of wine has trended generally upward through the 20th century and early 2000s to a peak of 250 million hectoliters in 2007, and remained stable ever since. This consumption drives a large sub-sector of horticulture – viticulture – that in 2017 accounted for 7.5 million hectares of land under vine and produced 73.3 million tons of grapes globally (Zion Market Research, 2018). Of this total tonnage, approximately 52% (38.1mt) is processed into wine while 42% (30.79mt) is destined for the fresh market and 7% (5.13mt) is dried to make raisins (OIV, 2018). 2018 was recorded as a record production year for wine with 293 million hectoliters made worldwide (Zion Market Research, 2018).

Expressing this production in terms of value, "the global wine market is expected to reach USD 423.59 billion by the end of 2023, growing at a CAGR [compound annual growth rate] of around 5.8% between 2017 and 2023" (Zion Market Research, 2018). To put this in perspective, it is estimated by the Food and Agriculture Organization of the United Nations (FAO) that 114mt of bananas – the second highest production fruit after watermelons in terms of overall tonnage - were harvested from 5.6mha planted worldwide in 2017, which had an estimated retail value of USD 20-25 billion (Food and Agriculture Organization of the United Nations, n.d.). Evident in this comparison is the significant value-add that occurs when fresh grapes are fermented and processed into wine: grapes are the most valuable horticultural crop in the world (Myles et al, 2011). As such, the global wine industry is a significant employer and economic driver for at least 18 of the top wine producing countries which constitute more than 99% of total production - though at least 80 other countries are known to grow grapes to lesser, but economically significant, degrees (OIV, 2018).

European wine growing countries (also known as the "Old World") including Italy, France, Spain and Germany have historically dominated production. "New World" players outside of Europe such as the USA, Australia, New Zealand, South Africa, Argentina, Chile and more recently China – now ranked 6th in terms of production and 5th in terms of consumption - have made rapid gains in the market in the last century (OIV, 2018). The wine industry is truly global in 2019, and many established producers in both Old and New World wine regions are having to grapple with the forces of globalization that are manifest as disruptions in what were, until recently, traditional, localized and well-understood, value-chains:

> *"The wine industry has changed dramatically in recent years. Decreases in tariffs, logistical cost reductions and the lowering of other barriers to international trade have provided producers the opportunity to sell their products outside of a limited region, as well as face competition from distant suppliers. Wines from around the world are desired and sought after by consumers. This new international access is reshaping how wines are produced and consumed alike, and those able to adapt to this wider playing field will gain significant competitive advantage."* (Cholette, Castaldi, Richard & Fredrick, 2005, p.1)

The International Organization of Vine and Wine (OIV) has noted that along with global competitiveness, the risks of venturing outside of your own traditional markets for distribution, and of competing for shelf space with an entire planet of wine producers at home are significant (Aurand, 2014). This is especially true for small, independent producers as environmental and resource concerns are increasing in global viticulture (Aurand, 2014). Grape growing has never been easy: crop specific pests and plant pathogens abound, and inclement weather events can affect the tender fruit clusters of the plant in particularly devastating ways as harvest approaches. Bacterial, fungal and viral pathogen spread has been facilitated by the rapid global exchange of plant materials in the 20th century. Climate models predicting cumulative temperature increases, concomitant volatility in weather patterns, and the migration of pests into previously unaffected areas are being borne out in the recorded data and seem to be threatening traditional cultivar selections and the viability of established farming techniques in many regions. Domestic and international labour systems are being disrupted by demographic, economic and political forces in this globalized world. Agricultural land use issues arise alongside many of the same disruptions. It is clear that the challenges facing the global industry in 2019 are in many ways substantial and unprecedented and will require both conventional and innovative knowledge, technology and effective organizational systems to overcome.

(*For a more detailed description of the history and evolution of Vitis vinifera, the wine grape, please refer to Appendix 7.1*.)

1.2 Ontario Grape and Wine Industry Overview

A 2018 survey of Ontario's grape growers and wine making community flagged "Foreign competition and the import of branded and bulk wine" in the top 5 of 15 ranked industry challenges (identified by the working group responsible for the study) by both medium ($0.5M-

2M) and large ($10M+) size processors. The study reveals that in addition to competitive pressure from foreign markets, growers and processors identify “rising input/labour/land costs,” “grape prices,” “grape supply” and “access to virus-free grapevines” as top concerns in a field that also gestured to regulatory, taxation, retail/distribution and infrastructure issues (VQA Ontario & Deloitte, 2019, p. 36). In many ways the Ontario grape and wine industry reflects the global industry in both its strengths and its weaknesses, but on a significantly smaller scale when compared to the top global producers.

In 2017, France produced 5.45M tons of wine grapes while Italy produced 4.99M tons and the USA produced 4.22M tons. China, the single largest grape growing nation, has an industry that skews heavily to the fresh grape market with 83% of its 13.7M ton grape crop sold this way and 6% sold as raisins, with only 11% or 1.5M tons to produce wine (OIV, 2018). By contrast to these world-class yields, in 2017 Ontario – Canada’s largest grape producing region - produced 85,539 tons of wine grapes, an all-time high for the Province (*See Figure 1*). 63,251 tons were grown in 2018, which is more akin to the average annual production when taken in the context of the last three decades, which is when the majority of wine grape acreage came online (Grape Growers of Ontario, 2018). Canada as a whole represents only 0.3% of global wine production, produced from approximately 31,100 acres of vines (Canadian Vintners Association, 2018). When you consider that exports of Canadian wine account for a mere 0.02% volume of global wine exports, it would appear that this is an industry of relative insignificance (Canadian Vintners Association, 2018).

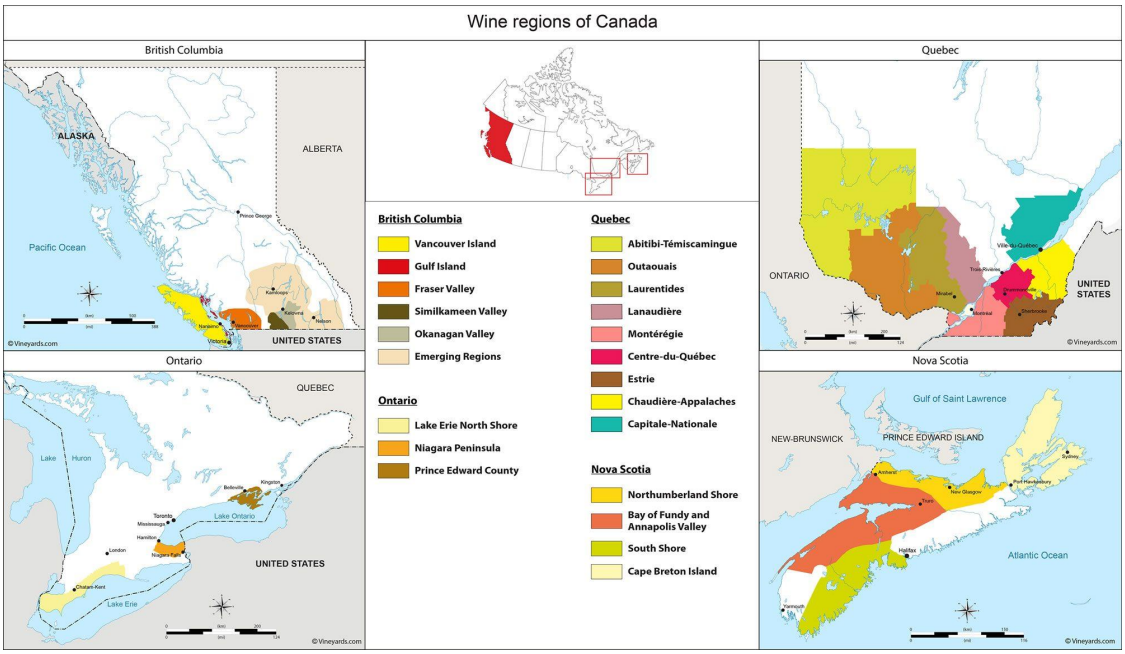


Figure 1. Wine Regions of Canada Map **(Vineyards Media LLC. 2020)**

By many metrics, however, the grape and wine industry has become important to the Canadian economy, particularly in localities which are conducive to viticulture such as the Great Lakes region of Southern Ontario and the Okanagan Valley in British Columbia. According to a 2015 report commissioned by the Canadian Vintners Association (CVA), the wine industry contributes $9.04 billion to the economy and provides 37,300 full-time equivalent jobs to the workforce (CVA, 2018). While this number includes the economic impact of associated industries such as tourism and hospitality as well as primary viticulture and beverage processing sectors, in the context of 2016 data from Statistics Canada indicating that the agriculture and agri-food system generated $111.9 billion of gross domestic product (GDP) in total, we may still reasonably conclude that the Canadian wine industry has grown into an important economic driver and employer (Agriculture and Agri-Food Canada, 2016). For every $1 spent on Canadian wine in Canada, $3.42 in GDP is generated across the country, an indication of the size of the value-chain involved (CVA, 2018). After blueberries and apples, grapes are currently the third most planted horticultural crop in Canada (Canadian Horticultural Council, 2016).

This growth is quite recent in the context of Canadian agriculture at large: in 1980 there were only 800 acres of wine grapes planted in Ontario. This has grown 20-fold in the three decades since (Grape Growers of Ontario, 2010). It is also worth noting that the average annual growth rate of total wine sales in Canada over the past 10 years was 4.2% whereas sales of Canadian wine grew at an annual average rate of 4.7% over the same decade, beating out sales of imported wine which increased at an average of 4.0% annually. This is in contrast to beer which has seen relatively flat growth at just 1.0% growth over the last 10 years. Export sales of 100% Ontario grown wines grew from 16,048,000L in 2014 to 19,050,000L in 2018 (Statistics Canada, 2019). While there remain numerous challenges to producing and selling wines profitably, including high input costs and taxation, the market for wine made from 100% Ontario grapes is strong - indeed, a larger issue for processors seems to be ensuring that a large enough supply of grapes exists, according to the Ontario Wine and Grape Industry Performance Study (VQA Ontario & Deloitte, 2018).

The Province of Ontario represents the largest concentration of wine grape plantings in the country with approximately 18,000 acres under vine. British Columbia follows with a little over 10,000 acres, while Nova Scotia, Quebec and the other Provinces contribute to a smaller degree (Canadian Vintners Association, 2018). The Vintners Quality Alliance of Ontario (VQAO) is the regulatory body which administers Ontario's wine standards for the production of 100% Ontario grape content wine and oversee labelling rules. The VQAO officially designates the majority of Ontario's wine growing regions into geographically delineated "Viticultural Areas" (VA's): the Niagara Peninsula, Prince Edward County (PEC) and Lake Erie North Shore (LENS). These regions are all located in the southernmost parts of Ontario, and Canada, at latitudes between 42°N-44°N (*See Figure 2*). Each region benefits to some degree from the cold-

moderating effects of one or more of the Great lakes, and the Niagara Region in particular tends to miss the most extreme winter temperatures due to its situation to the South of Lake Ontario, which allows for air moving south from the arctic north to warm up as it crosses the lake and enters the grape lands. This factor in combination with a relative abundance of flat, fertile soils has resulted in the bulk of production being centered in Niagara with an average of 20,876,787L of wine being produced annually versus 270,549L in LENS and 264,699L in PEC (Vintners Quality Alliance of Ontario, 2019).

Figure 2. **Ontario Viticultural Areas Map (VQA Ontario, 2019)**

1.3 Threats and Challenges to the Ontario Grape and Wine Industry

The Canadian grape and wine industry has seen steady economic growth and considerable, definitive success in the last decades, but significant threats to the health and sustainability of the viticultural foundation of the industry are apparent. These reflect many of the issues facing grape growers internationally as outlined above, but also have their own regional specificity. In general, these Viticultural Areas provide many of the essential environmental growth factors associated with growing good quality wine grapes: a temperate latitude between 30-50°N/S; an adequate frost free period that delimits the growing season and allows for many types of wine grape cultivars to fully ripen; enough heat and sun accumulation in the growing season to adequately ripen a crop of sufficient economic yield, and also allow for energy storage to get

the plants through the dormant period; and sufficient precipitation, ground water and suitable soils for viticulture. There are, however, limitations to growing grapes in even this most moderate (Plant Hardiness Zone 7a) of Canadian growing regions (*see Appendix 7.2 for explanation of Canada's Plant Hardiness zones).*

1.3.i Climatic and Environmental Issues

The regular incidence of extreme sub-zero temperatures in winter definitively shifts Ontario's Viticultural Areas (VA) to the margin with regards to climate suitability for wine grapes. Late frost in spring and early frost in fall also represent major environmental threats, as do excessive precipitation and humidity in the growing season (Willwerth, Ker & Inglis, 2014). Excessive moisture in the soil and canopy contribute to high disease pressure in Ontario relative to many other grape growing regions, particularly from fungal infections including powdery mildew, downy mildew, black rot and bunch rots such as botrytis and sour rot (Agriculture and Agri-Food Canada, 2016). Turbulent weather patterns associated with hurricane activity on the Atlantic seaboard can bring substantial rains in the harvest months of September and October resulting in the rapid breakdown and decline of an otherwise healthy crop due to cluster rots.

1.3.ii Land Issues

In addition to these environmental and climatic pressures, a distinct set of challenges facing the Ontario grape and wine industry can be broadly categorized as *land availability, use and pricing* issues. The cold temperature sensitivities of *Vitis vinifera* outlined above effectively limit wine grape production to a few tiny areas relative to the large amount of land in Canada available for more cold-hardy fruit crops such as apples or blueberries. Urban development in what have become desirable places to live (i.e. "wine country") and the decline of the family farm have also led to a loss of agricultural lands in these regions. Population increases and a decline in available housing in the Greater Toronto Area (GTA) has resulted in population migration and settlement out of the urban core and outward toward the Niagara and PEC wine regions. Niagara in particular is just a little over 100km from the urban center and 2016 census data shows that Niagara's growth rate exploded by more than 300 per cent between 2011 and 2016 compared to the previous five-year period (Forsyth, 2017).

The Niagara VA faces several distinct challenges relating to its situation in the heavily urbanized, population dense "Greater Golden Horseshoe" region that rims the southern end of Lake Ontario. Residential neighbours often take issue with cold weather mitigation and disease and pest control methods and technologies. The noise generated by wind machines that stave off frosts, and propane bird cannons are ongoing points of contention in wine country, while pesticide application and drift is cause for much concern amongst many residents. As such, the notion of social sustainability becomes a key element in any viticulture-related business plan. There is increased lobbying from land developers for allowances to develop agricultural lands

with a mind to leveraging the "wine country" brand as well as the temperate climate. Offshore investment in vineyards and wineries, most often from China, and competition for land from new agricultural industries such as cannabis – Canopy Growth Corp. recently purchased a 60 acre vineyard in the Niagara Region to control property adjacent to their greenhouse complex, for instance – have also contributed to the price inflation of viable grape land.

1.3.iii Labour Issues

Compounding the high production costs that Ontario's grape growers incur due to a marginal climate and having to plant on expensive land, there is an acute labour shortage in vineyards that is common to the agri-food sector in Canada in general, but that poses unique challenges to viticulture because agricultural practices and market demands for wine grapes are specialized in many ways. Broadly speaking, a recent study by the Canadian Agricultural Human Resource Council estimates that by 2025 there will be 114,000 more agricultural jobs available than can be filled by domestic workers (Canadian Agriculture Human Resource Council, 2016). This poses a significant risk of losing billions of dollars on productivity in the economy: the same study calculated that in 2014, 7% of agricultural jobs went unfilled, leaving $1.5B in lost sales behind (Canadian Agriculture Human Resource Council, 2016). This phenomenon will affect Ontario to a larger degree than any other Province with an estimated 46,000 agricultural jobs going unfilled by 2025 (Canadian Agriculture Human Resource Council, 2016). This is a complex problem related to demographics, the governmental and the regulatory environment, as well as cultural, social and employment patterns and trends.

On the whole, it becomes apparent that the challenges facing viticulture in Ontario are complex, dynamic, and urgent. A comprehensive, cohesive and multifaceted response on the part of industry stakeholders becomes necessary. This project endeavors to consider one important aspect of this response: the education and training of front-line workers in Ontario's viticulture industry. It is my opinion, informed by my role as vineyard manager and winemaker at the Niagara College Teaching Winery and as an instructor in the wine programs at the Canadian Food and Wine institute at Niagara College, that an organized and deliberate cluster of activities that include research and data acquisition and interpretation, knowledge transfer, and worksite application through skills training has the ability to address many of the challenges laid out above in a direct way and help the industry grow and thrive into the future.

1.4 Objectives of this Study: Education and Training as a Means of Addressing Challenges in the Ontario Wine Industry

The objective of this report is to (i) identify and assess the current needs and challenges of the viticulture industry in Ontario; (ii) to consider solutions to these challenges in and through

observations made in the course of my travels to a variety of global wine regions and viticulture schools; and (iii) consider ways that education and training programs in Canada can help address these domestic needs by supplying a labour force to the industry with the most relevant skills and abilities to address these issues. A survey of a variety of world-class international program models was conducted with lessons in success demonstrating possible avenues for improvements in viticulture education and training programs in Canada.

1.5 Viticulture Education: Historical Survey and Canadian Context

It is worth noting that before the Dutch tradesman Antonie van Leeuwenhoek observed tiny spheres under an early microscope with good quality lenses in 1680, no human had ever seen, let alone understood, the microbiological mechanism by which fermentation – the biochemical conversion of sugars to ethyl alcohol and other byproducts - occurs. It wasn't until 1876 that Louis Pasteur was able to identify fermentation as a metabolic process that occurs inside yeast cells, which he described as "respiration without air" (Alba-Lois & Segal-Kischinevzky, 2010). Throughout the millennia of making wine, various cultures had determined best practices for wine production. It was known that a dark environment, cool temperatures and tightly sealed vessels helped stave off spoilage, for instance, and so technologies like ceramics, cork closures, wax and lead sealants, floating layers of oil on the surface of wine and deep, excavated cellars or caves were employed in the service of vinification in various times and places. True wine science, or "oenology" could only begin with Pasteur, however. Similarly, no one had ever seen a plant cell until Robert Hooke described the appearance of a piece of cork under his microscope as resembling the small rooms that monks lived in, termed "cellula" (Rhoads, 2017). With the work of Carl Linnaeus and others in the 18th C., followed by that of Charles Darwin and a series of technological developments including the invention of the light microscope in the 19th C., the plant sciences became more formalized.

Viticulture and Oenology research facilities and academic and applied training programs were, for the most part, institutionalized in Europe as specialized fields distinct from biology, chemistry and the plant sciences in the second half of the 19th C. A National School of Agriculture that included viticulture studies was initiated in Montpellier, France, in 1870, while the Lycee Viticole de Beaune was formed in Burgundy, France, in 1884. Italy saw similar research stations and academic programs form in this same period with the Istituto Agrario di San Michele all'Adige (IASMA) or Edmund Mach Foundation opening in 1884. In 1882 research and training in viticulture began at Geisenheim University in Germany. On the other side of the Atlantic, the University of California established a research center for grapes at Berkeley to support a burgeoning wine industry in 1880, which would later move to Davis in 1935 following the repeal of prohibition. The 1880s also saw the University of Stellenbosch in South Africa

offering academic programming in viticulture and oenology. Each of these programs arose as a means of addressing contemporary challenges and threats facing regional wine industries such as the phylloxera epidemic (a devastating global infestation of microscopic aphids which feed on roots and foliage and eventually kill the vine), the appearance of powdery and downy mildews in Europe and securing supplies of disease-free nursery stock for industry growth. These institutions would all become instrumental in supporting the growth and development of their regional grape wine industries.

A leading viticulture consultant and educator in Ontario, Dr. Kevin Ker, addresses the need for education and training institutions to support the grape and wine industry in the Canadian context in his doctoral thesis, pointing to the notion of a labour and knowledge gap that must be closed for any wine region to be successful:

> *"Acquiring knowledge and skills in this [wine] industry can occur formally via institutional learning programs (university or college) or informally through direct employment and learning on the job... The shortage of skilled and knowledgeable labour has been identified as a limiting factor for continued expansion of the industry and efforts to improve grape and wine quality, especially in emerging regions"* (Ker, 2010, pp. 2-3).

In reviewing education and training options worldwide in the course of this study, it is clear that "informal" on-the-job training remains very important in viticulture, as it does in almost any agricultural sector, but that many different types of "formal" options exist as well. Online learning formats are becoming more and more popular, and College or University "Extension" offerings – a distillation and re-packaging of diploma or degree program content designed to provide industry professionals or those interested in getting into the industry with some key knowledge and training – are becoming more widely available in some regions. For those with time, money and inclination, full-time applied/technical diplomas and higher level undergraduate and graduate degrees in viticulture and oenology are available at many institutions globally.

The relative youth and small size of Canada's "emerging" wine industry when compared to larger, more established regions has meant that modes of formal education in the grape and wine sciences have come along only recently in our provinces, and remain somewhat limited. Brock University in St. Catharines, ON, established its Cool Climate Oenology and Viticulture Institute in 1996 to support the Ontario industry with regionally applicable research, student training and outreach/extension knowledge transfer offerings. In the year 2000, Niagara College (where I am currently employed), located in Niagara-on-the-Lake, ON, started a two-

year applied training diploma program which benefits from on-campus facilities that include tasting labs, vineyards and a commercial scale working winery alongside scientific labs and classrooms. Both Nova Scotia Community College, in Nova Scotia, and Okanagan College, in British Columbia, currently offer certificate courses in Oenology and Viticulture. Okanagan College has run a pilot program to determine whether they will proceed with a fully accredited viticulture diploma program in 2020. The University of British Columbia, which operates the Wine Research Centre in Vancouver (started in 1999) and Dalhousie University have conducted research into viticulture and oenology topics in and through their Faculties of Agriculture, Engineering and Chemistry.

While these institutions have helped bolster the nascent wine industry in Canada, and while the current industry is populated by graduates from all of these programs, there remain skills and labour gaps in the space between the programs and the industries they support. This report endeavors to look at these gaps in some detail, to consider possible solutions and to make recommendations for improvements to stakeholders including the above mentioned institutions.

1.6 Methods

In the context of this Nuffield project, I set out to explore how world-class viticulture training programs located in established commercial grape and wine growing regions best serve, support, and collaborate with those industries that they supply with skilled labour. In the course of the project I visited research and training facilities in 9 countries and attended conferences in Canada, the United States, Spain and Scandinavia where a diverse field of teachers and academics were in the same room together, allowing me to meet people from many of the regions and programs that I did not have the time or resources to visit in my Nuffield travels. All of the schools and research centres that I visited were located in well-established wine regions, and most had long histories in the specialized fields of viticulture and oenology studies.

While the Canadian and Ontario wine industry has developed quickly, benefitting as we do in this country from a high level of political and economic stability and development, I determined that there would be many lessons to be learned from mature, larger wine industries, such as those found in France, Italy, Germany, South Africa and the United States. I examined the curriculum structure and content of a wide range of these international programs to understand how they might be addressing specific needs and challenges in their local industries and to consider what subject matter was considered most relevant in those regions. I spoke with representatives from those institutions as well as various stakeholders from the grape and wine industries in those regions to better understand the dynamics between them. I looked for

patterns and trends and commonalities across these diverse regions, and for lessons in success that would translate back to the Ontario wine industry in order to formulate relevant recommendations and guidelines for viticulture training in our own grape industry. My hope is that this material will be relevant to both formal and informal education and training systems.

2.0 DECANTING KNOWLEDGE: HEADY LESSONS FROM THE WORLD OF WINE

2.1 The Climate Challenge: "You make wine in *Canada*?"

An average wine drinker in France or Italy, or even in California, , likely has no idea that we grow wine grapes in Canada. Wine is not a traditional product here, nor is it a large export product in the global context. These same consumers likely have other perceptions of Canada, however. They might be aware that we produce a lot of maple syrup, lumber, grains and meat. They might assume that we drink a lot of light beer while playing hockey. They will almost certainly imagine that most of this occurs against a backdrop of snow and ice: the "Canadian North." Wine comes from warm, sunny, gentle climates - from Provence, from California, from South Africa's Western Cape - not from the Canadian North: "You make wine in Canada?" This is often where the conversation starts with a stranger on an airplane or train after I mention what I do for a living.

Well-travelled, well-read wine professionals like the educators and producers I visited in the course of this scholarship know a little more about Canadian wine, though often only a little: "You make *Icewine* in Canada, right?" The idea of "the North" permeates any notion of Canadian viticulture because the diversity of styles being produced in Canadian wine regions above and beyond our iconic dessert wine, which is indeed picked in the middle of winter, are simply not available without a visit to our country's wine regions.

In truth, there is some validity to these perceptions of climate: cold temperatures in winter, early or late frosts and a sometimes limited growing season define viticulture in Canada in terms of which cultivars and rootstocks may be used. There are many moderate to warm climate-loving grape varieties that simply won't grow in Ontario. Extreme cold temperatures represent a critical, persistent threat to sustaining economically viable grape growing operations. At -18°C to -20°C many popular, but cold-sensitive cultivars such as Merlot, Sauvignon Blanc or Syrah will suffer from bud and trunk damage and the resulting crop loss and vine remediation costs will result in profit loss in these blocks. At -20°C to -25°C virtually all *Vitis vinifera* cultivars will suffer substantial tissue damage leading to complete devastation for growers (Ontario Ministry of Agriculture, Food and Rural Affairs, 2019). Such damage is common in all of Canada's grape growing regions, and successful growers must find ways to mitigate the effects of our cold climate on the vines.

The second most significant environmental threat to Ontario viticulture relates to excessive moisture. The difficulty of accessing and working wet ground, along with high levels of disease pressure associated with heavy rainfall, stagnant ground water and high humidity must be dealt with in an ongoing way, particularly on the poorly-drained, heavy clay soils that dominate a large part of Niagara's grape lands. At the same time, certain weather patterns will also bring drought conditions to Ontario in the growing season in some vintages, so the water problem becomes more complex and potential solutions require access to good science and technology ahead of implementation.

To complicate this further, research suggests that weather patterns in Ontario's grape lands are evolving as a result of global "climate change" effects (Stocker et al., 2013). Climate change is a phenomenon that is widely recognized by the scientific community and which describes a warming trend driven in large part by human activities which release greenhouse gases - especially carbon dioxide - into the atmosphere (Stocker et al., 2013). The Intergovernmental Panel on Climate Change (IPCC) is the United Nations body for assessing the science related to climate change. The 5th and most recent assessment report from the IPCC notes that "the globally averaged combined land and ocean surface temperature data as calculated by a linear trend, show a warming of 0.85 [0.65 to 1.06] °C, over the period 1880 to 2012" (Stocker et al., 2013). Thousands of studies show that both the atmosphere and ocean temperatures have warmed, the amounts of snow and ice have contracted, sea levels are rising, and overall the concentrations of greenhouse gases have increased since industrialization. Projections are highly dependent on greenhouse gas emissions activity in the near future, but the best available models suggest the following:

> *"Relative to the average from year 1850 to 1900, global surface temperature change by the end of the 21st century is projected to likely exceed 2°C for [model] RCP4.5… It is virtually certain that there will be more frequent hot and fewer cold temperature extremes over most land areas on daily and seasonal timescales as global mean temperatures increase. It is very likely that heat waves will occur with a higher frequency and duration. Occasional cold winter extremes will continue to occur"* (Stocker et al., 2013, p. 20).

The economic and social impacts of this will be highly variable depending on the particularities of geography, but it is well understood that there will be large impacts on grape growing industries across the globe.

The effect of climate change on grape growing is therefore a significant research area in all grape growing countries, including Canada. A recent report from Natural Resources Canada (2019) shows evidence that the average temperature in Canada is increasing at twice the rate of the global average. Dr. Anthony B. Shaw, a Geographer from Brock University, has studied the likely effects of climate change on the Niagara Region extensively, including effects on the grape crop specifically. His findings may be summarized as follows:

- Winters will become warmer.
- The severity of spring frosts will decrease.
- Summers will become warmer.
- There will be a higher frequency of days with extreme maximum temperatures.
- There will be an increase in water usage by the vines and, by extension, the growers.
- There will be a decrease in precipitation in the spring and summer months.
- There will be more volatility in the growing season therefore more variable yields, ripening and grape/wine quality between vintages

(Shaw, T., n.d., 26-30)

Some of these effects may be viewed as a net positive from the perspective of grape growing: more heat and a longer growing season will expand the range of where wine grapes may be planted, opening up land to the north of the existing Viticultural Areas, and will allow heat-loving cultivars to ripen more fully than they currently do. Popular cultivars such as Cabernet Sauvignon or Merlot which may be thin-bodied and vegetal in taste due to insufficient ripening will be picked with higher sugars and make fruitier, bigger-bodied wines that appeal to the mass market in a way that is not currently possible. The number and distribution of cultivars will likely diversify as the area suitable for growing grapes is enlarged, allowing for variation and specialization of wines and styles and access to potential new markets.

At the same time, according to Shaw, a number of risks accompany this warming trend: there will likely be reduced yields due to drought or near-drought conditions in many areas, necessitating capital expenditures in irrigation systems where it was not previously required. There will likely be an influx and increase in both indigenous and migratory pests and diseases that were previously limited or excluded by cold winters. Areas which were once suitable for cool-climate cultivars, especially white grapes such as Riesling of Sauvignon Blanc, will no longer be able to produce high quality grapes due to the loss of natural acidity and overripe or “cooked” flavour development, which will require adaptations to winery business models. Most importantly, unpredictable weather and an increase in extreme weather events including heavy

rain, wind storms, hail, drought, heat waves or extreme temperature drops become very difficult to adapt to and manage for growers (Shaw, n.d.).

Bruce Zoecklein, Professor Emeritus at Virginia Tech, puts it this way: “Vintage-to-vintage variations are likely to become much greater, as seen throughout the world. It is not climate change, per se, that will affect some, but the erratic nature of the unpredictable weather that may be a greater problem” (Zoecklein, 2018). How then do we address the risks to the grape growing industry from existing, well-understood conditions such as the cold and disease, on the one hand, and extreme weather events in a future which is tending towards an unstable climate, on the other?

2.1.i Addressing Climate and Environmental Challenges with Technology and Information Systems

I was able to visit Dr. Justine Vanden Heuvel, professor of Horticulture (a faculty which includes viticulture) and some of her colleagues at Cornell University’s Viticulture and Enology program on a cold day in December. The Ivy League school is located in the Finger Lakes Region of Upstate New York which has many of the same issues with cold and humidity that Ontario’s wine regions do. The maxim at the school is, “If you can make good wine here, you can produce it anywhere,” which may as well apply to Ontario’s winegrowing regions as well. The challenges arising from farming grapes in a truly cold climate sets both of these regions apart from the majority of wine producing regions which tend to be located in milder climates. Cornell engages with these challenges in research labs and classrooms with a high degree of effectiveness. Courses in commercial grape production have an emphasis on issues surrounding production in cold climates. High level theoretical material is bolstered with internship credits which add experiential learning opportunities in commercial wineries and vineyards to the undergraduate program. In speaking with Russell Moss, a viticulture lecturer who worked in commercial grape growing in California, Oregon, France and New Zealand before settling into academia at Cornell, I was informed that he was hoping to enhance the level of experiential learning within the curriculum of the undergraduate program itself to better prepare graduates for the real-life working world outside of the classroom. To that end, he was in the process of designing hands-on vineyard design and trellis installation labs and training his classes in the use of innovative vineyard mapping software (Moss, 2018).

Examples of Dr. Vanden Heuvel’s own work include researching ways of optimizing wine grape production by using computational tools. “Nondominated sorting genetic algorithms” are used to provide quantifiable data to guide decision-making and account for multiple production objectives at the same time such as yield, vine health and labour or materials inputs. Some of her work also addresses the environmental sustainability of common production methods

(Vanden Heuvel, 2018). Similar to Ontario, high humidity and vigorous soils often lead to high fungal disease pressure in the Finger Lakes, resulting in large amounts of chemical fungicide being used. The effects of this chemical usage are being studied in conjunction with canopy and soil management techniques to establish best practices to both address disease incidence while mitigating harm to the soils and environment, and the results of this work will be very relevant to the Ontario industry.

Just as impressive as the hard-core research occurring at the various labs at Cornell, was the knowledge transfer occurring through their Outreach and Extension programs which are mandated with helping to grow and support the commercial wine industry in New York and beyond. Numerous workshops, newsletters and collaborative vineyard trials with clear application goals are provided throughout the year to address such pressing issues as grapevine virus incidence and management, sustainable production and the effect of climate and cultural practices on fruit yield and quality. The strength of the Extension programs seemed to lie not only in the primary research base available, but on collaboration between researchers and faculty from different departments (horticulture, chemistry, engineering etc.) and industry stakeholders to identify key issues that need addressing. Examples of useful Outreach services include a winter Bud Hardiness Monitoring Program to identify incidence of plant tissue damage and inform management practices, their “Enocert” program which offers short courses “intended for current winery employees who would like to expand their practical knowledge of winery operations, or for motivated amateurs,” a webinar series called “Clean Plants for the Future of the Eastern Wine and Grape Industry,” addressing nursery-transmitted grapevine pathogens and numerous newsletters and online articles written in non-technical, accessible language (Cornell College of Agricultural and Life Sciences, n.d.).

A really fascinating initiative in which Cornell has partnered with the Institute for the Application of Geospatial Technologies is called the New York Wine and Grape Foundation. This project has compiled data to create an interactive GIS map-based system for evaluating vineyard mesoclimate and site suitability for grapes. The economic return on planting grapes is a long term proposition since it typically takes three years to get a first crop, and site selection requires consideration of a plethora of factors including temperature, soil pH/depth/drainage/fertility, topography, slope, aspect, proximity to water, and others. Data is sourced from multiple sources such as the US Natural Resource Conservation Service and NY State agencies, The Northeast Climate Center at Cornell University, Cornell University grape specialists and grape growers themselves, to provide a highly practical tool to help guide planting decisions in the region. The viticulture education cluster at Cornell manages to serve the grape and wine industry in the Northeastern United States by offering multiple education and training options in a wide variety of formats to accommodate diverse needs in the

commercial industry. Broadly speaking, my Nuffield travels seemed to affirm that successful grape and wine industries worldwide tend to rely on the support of such institutional resources.

On the other side of the Atlantic, researchers, faculty and students at Hochschule Geisenheim University in Germany are similarly preoccupied by environmental and climatic effects on grapevine physiology and fruit quality. The undergraduate program delivers curriculum in both traditional grape growing skills and knowledge such as ampelography, vine pruning and canopy management, with cutting edge viticulture approaches such as autonomous robotics equipped with non-invasive sensors and artificial intelligence systems. A group of experts from Geisenheim in conjunction with other universities and private companies have also researched and developed automated grape-sorting technology and the equipment has been commercialized with the company Rotovib. The grape sorter uses high-speed cameras to identify, and mechanical actions to separate, materials such as leaves, twigs and bugs from intact grapes after harvest. Work is continuing to establish associations between light wavelengths in the Near Infrared Range (NIR) with quality parameters in the grape berries such as sugar levels, which could allow for selection and separation of fruit with variable ripening levels (Armbruster, n.d.).

I spent a hot day in July with Dr. Joachim Schmid from the Department of Grapevine Breeding and Dr. Matthias Schmitt from the Department of Oenology. Dr. Schmid suggested that the summer had been generally too hot for the Riesling grape which constitutes 80% of all plantings in the Rheingau winegrowing region where the University is located. As a high latitude, cool climate wine region, Germany, like Ontario, will likely see expanded planting areas open up due to climate change effects in the 21st C. At the same time, with increased ripening the wine styles are changing with higher sugars and lower acids which is requiring adaptations by growers and consumers alike. Summer drought has become an issue in many parts of Germany. Part of the difficulty with anticipating the effects of climate change on specific crops in specific regions is that available models usually account for relatively large geographical areas and so the complex particularities of climate change on a small grape growing region like the Rheingau are not necessarily accounted for fully. This fact is true for any winegrowing region including Ontario: fundamental business decisions with serious economic implications for this generation of growers and the ones that follow such as deciding which cultivars should be planted in which sites rely on an understanding of how climate and weather is likely going to behave in the future.

Researchers at Geisenheim are addressing this issue in what is called the “FACE” project. They have designed a simulated ecosystem around Riesling and Cabernet Sauvignon grapevines in one of their research plots that mimics an anticipated increase of CO2 levels by 20% in the atmosphere by the year 2050 (*See Figure 3*). Six rings of ventilators 12 meters in diameter blow carbon dioxide into the grape rows. Wind direction and speed monitors help the ventilators

distribute the CO2 throughout the test areas. Three ventilation rings also blow normal air on a part of the plot to provide controls for the experiment. Up to this point the data collected has been substantial, with significant, measurable changes observed in the treated crop. The additional CO2 is making the grapes bigger and juicier while the vines are taking up much more water from the ground. An insect pest called the Grape Berry Moth has proliferated under higher CO2 levels also.

Figure 3. **FACE Project, Geisenheim, Germany (Hochschule Geisenheim University, (n.d.))**

There are numerous sub-projects attached to the FACE program that are looking into vine physiology and fruit yield, resource management and water supply, vine stress factors and greenhouse gas emissions from soils (Schmid, 2018). Related to this, another collaborative project by what is called the “BAG” (Bordeaux-Adelaide-Geisenheim universities) Alliance is called the "Heat Berry" project which focuses on the effects of temperatures and radiation – both expected to increase in the next decades - on biochemical substance production in grape berries which relate to wine quality. There appears to be an urgency to this research which is driving funding and partnerships in both cool and warm climate viticulture regions as represented by the partner institutes in this alliance, and Ontario would be wise to take note of this urgency and ensure funding and support for our own climate research initiatives.

Further south, in the Languedoc-Roussillon region of France, climate change is forecast to have a more disastrous effect than it will have in most northern latitudes. What is already a hot and dry climate may become truly inhospitable to grape production as we know it, as temperatures exceed conventional physiological thresholds for this species (Ponti et al., 2018). Researchers at

Montpellier SupAgro alongside scientists from the National Institute of Agricultural Research (INRA) are working hard to understand how to avoid the most devastating effects on the grape crop. I met with Patrice Lallemand, director of the Euromaster Vinifera Program, to discuss how the Montpellier SupAgro connects undergraduate and graduate programs to this research work. He and his colleagues consider the gamut of production, from grape to packaged wine. Beyond traditional oenology and viticulture topics, a lot of resources are being dedicated to researching soil ecology in conjunction with cultural practices such as pesticide use, tilling, and cover crops. Other important topics at the school include efficient vineyard design, low-input farming systems, environmental impact assessments and new, innovative vineyard technology, as well as traceability in the production chain. A major focus is on water use management and methods to delay ripening to help growers adapt to the changing climate conditions. INRA researchers are invited into the classroom to present their research findings directly to students, and International Masters program students spend lab time visiting INRA research facilities at vineyard sites outside of Montpellier (Lallemand, 2018). While Ontario's vineyards often suffer from excess water rather than a lack of it, the erratic nature of climate change may well lead to more drought years and extreme heat events, so lessons in vine management from hot regions such as Montpellier may soon become applicable in our own context. This may be especially important in British Columbia's Okanagon Valley which already suffers from hot, arid conditions in the growing season.

At the other end of the climatic spectrum, the content of a cold-climate viticulture conference held in Denmark and Sweden called VitiNord reaffirmed the significance of climate change to the grape and wine industry. Dr. Kimberly Nicholas from the Lund University Centre for Sustainability Science noted that even when growing grapes remains viable, higher temperatures are already understood to result in lower priced wines. This is a reflection of the way that wines from fast-ripening and over-ripened grapes are perceived to be of lower quality than wines from grapes that ripen slowly and steadily and maintain flavour and acidity at moderate sugar levels. She also noted that adaptations, such as implementing irrigation as regions heat up, become more ineffective with higher temperatures. Dr. Nicolas suggests that the first and best strategy to mitigate damage to the wine grape industry is to stave off climate change as much as possible by limiting greenhouse gas emissions. As such, a key responsibility of all industries including viticulture and winemaking is to find ways to reduce energy consumption and emissions (Nicholas, 2018). Dr. Nicholas noted that vineyard and winery operations can prioritize rail and ship transport over truck and air, look at lightweight packaging options, optimize inputs such as nitrogen application, and consider energy efficient building design and focus on using renewable energy sources. These are all things that may be practically implemented in the Canadian industry and in the classroom in Canadian viticulture programs.

Another speaker at this conference, Professor Emilio Gil from the Department of Agricultural Machinery at the Universidad Politécnica de Cataluña in Spain discussed methods for addressing high fungus pressure in grape crops using spray application technology including variable rate application and GPS guidance for sprayers, as well as flexible and adaptable precision air patterning on spray blowers and modern nozzle styles including air induction. Specific examples of such units were included, many of which have not yet been introduced to the Canadian market. His research has resulted in a software application tool called Dosaviña® which can be used on a smartphone to determine optimal volume rate and calibration of specific equipment for pesticide spray application in trellised vines based on mapping of "Leaf Wall Area (LWA)" or canopy with land vehicle or Unmanned Aerial Vehicle (UAV) – mounted optical technologies such as Normalized Difference Vegetation Index (NDVI) or LiDAR (Light Detection and Ranging) sensors (Gil, 2018) (*Please see appendix 7.3 for illustration of this technology*). While NDVI and LiDAR technologies have been used to assess growth performance patterns and trends in Ontario vineyards, it has not yet been connected to real-time operations such as spraying or leaf removal, likely because this technology is not well understood by most growers and due to capital costs.

A discussion of what the Ontario wine industry is lacking in terms of knowledge, technology or labour gaps must be prefaced by noting that there are numerous successes that belong to Ontario grape industry stakeholders in finding solutions for addressing climate and environmental pressures. A search for practical solutions to combat difficulties associated with a cold and wet climate (if not a future, erratic climate) is evident in the Ontario industry already. A George Morris Centre study from 2010 which surveyed industry stakeholders including growers indicated that:

> *"There is a latent interest among growers to invest further in labour saving and quality improving technologies, notably mechanized thinning and leaf removal equipment and technologies to mitigate winter damage. The growers can envision more of a focus around varietals that grow well here and quality improvements that they are compensated for" (Mussell et al, 2010, vi).*

In the years following this study, Ontario grape growers have adopted a wide range of useful management technologies to combat difficult growing conditions. Having surveyed many notable wine regions in the course of my Nuffield project, it seems clear that Canada, along with some of the more northern winegrowing states in the U.S., has a greatly advanced knowledge of cold-climate viticulture relative to a large part of the globe and that growers are in general quite willing to consider adopting new technologies. As an example, a key tool

against cold weather tissue damage are wind machines, which have been widely used in Ontario since the late 1990s. These are designed with large propellers mounted on towers that are angled slightly downwards and are capable of pulling warm air that has risen above the ground down to crop level, raising temperatures around the vines to stave off killing frosts or deep freezes (Ontario Ministry of Agriculture, Food and Rural Affairs, 2019).

Geotextile fabric is another technology that is showing good success in mitigating cold damage in winter. This permeable fabric can be laid over the dormant vines in winter and fastened tightly to the ground, providing an insulating layer in conjunction with the soil against the ambient temperature (Willwerth, 2014). It seems possible that local research confirming the efficacy of geotextile fabric may lead to wider adoption of the technology, emulating the success of wind machines. Similar to Cornell's Bud Hardiness Monitoring Program, researchers at Brock University have also provided a very useful data systems response to cold climate conditions with their VineAlert outreach program. Growers have access to regular bud hardiness reports for major wine grape varieties across all significant growing regions in the province. This information may be used to assess the risk of winter injury throughout the dormant season to inform pruning and other management decisions (Cool Climate Oenology & Viticulture Institute, n.d.).

Modern management equipment such as mechanized leaf removal and canopy hedgers and modern pesticide sprayers, have also already been implemented widely in Ontario vineyards and go a long way in addressing some of the disease problems associated with our high moisture environment. Grape sorting systems similar to the Rotovib are also available in the Ontario market. There is even more innovative technology being manufactured today that will produce greater control and efficiency in terms of canopy adjustments and in terms of chemical volume and coverage needed to combat disease pressure, so it is incumbent on any training program in Ontario to ensure that its curriculum anticipates the arrival of new and useful tools such as these.

The climate change forecasting work initiated by Dr. Tony Shaw at Brock University has helped to lay the groundwork for a project that aims to specifically identify the most appropriate clone-rootstock combinations in a changing Ontario climate. Dr. Jim Willwerth and others at the Cool Climate Oenology and Viticulture Institute at Brock University have planted research plots with the support of the Natural Sciences and Engineering Research Council of Canada (NSERC) and Ontario Grape and Wine Research Inc., along with private growers. This project is designed to assess the performance of specific planting stock with reference to cold hardiness, vine phenology and fruit and wine qualities. Initiatives such as this, which are so apparent at many of the institutions that I visited during my Nuffield project, will prove invaluable to our industry in the long run, particularly as the climate shifts in potentially unpredictable ways. The hope is that more funding and resources can be directed to widen the scope of such projects.

It may not be enough to simply be able to forecast climate change effects and trial stock that has some resilience in the face of these effects: stakeholders of the Ontario wine industry need to be aware of climate science at large and do their part to help mitigate any potential damage. To borrow a didactic tool from her talk at the VitiNord 2018 Conference, the phenomenon of climate change and human engagement with its effects can be distilled as follows:

- "It's warming."
- "It's us."
- "We're sure.
- "It's bad."
- "We can fix it" (Nicholas, 2018)

Point number five is where the academics that I met, and the students they instruct, fit in. We should expect the Ontario viticulture industry and the academic programs that support it to place a higher value on understanding climate science than we have up to this point. This includes the formulation of curriculum that addresses ways to fundamentally limit greenhouse gas emissions within the scope of everyday grape growing and wine production operations and to also point towards strategies for resilience in the face of climate change.

Projects such as VineRobot and FACE at Geisenheim and the computational modelling technology discussed at Cornell hint at areas that can be further developed in our own industry, as vineyard management decision-making is still largely traditional in Ontario vineyards. While remote sensors are occasionally used for weather data collection, complex algorithmic tools to guide management decisions are not currently in use in any significant way. As these technologies move from the research lab to commercialization it may be hoped that they be widely adopted given the willingness of a substantial portion of Ontario's growers to implement new technologies.

What is certain is that present and future viticulturists in Ontario will have to be extremely tech-literate and that academics and researchers in the Ontario industry will play an ongoing role in helping translate high level science and demonstrate the functional application of these mechanical and data-systems innovations. The vineyard manager of the future will have to be fluent in a wide variety of mechanical and digital technologies that simply didn't exist a decade ago, and that are evolving rapidly. The way we grow grapes will change just as rapidly in the next ten years. Vineyard managers will be expected to have a working knowledge of GPS/GIS mapping software such as ArcGIS and a facility with a variety of remote sensing systems including weather sensors and reflectance spectroscopy, including Unmanned Aerial Vehicle mounted systems. The ability to use specific proprietary software to collect, organize and

interpret the data collected will also be crucial to the job, and therefore these skills will have to be taught in post-secondary education programs.

2.1.ii Keeping our Options Open: Breeding Programs and Cultivar Selection

I met another well-known viticulture researcher at the Terroir viticulture conference In Zaragoza, Spain. Cornelius van Leeuwen from the University of Bordeaux has said that:

> *"Growers need to implement adaptive strategies to continue the production of high-quality wines at economically acceptable yields in a warmer and dryer climate. Among various options, the use of adapted plant material is one of the better tools, because it has the advantage of being environmentally friendly and cost effective" (van Leeuwun & Darriet, 2016, p. 164).*

Availability of strong, healthy plant material has always been important to sustaining growth in wine regions, but never more so than now. As climate and weather patterns change, so must cultivar and clone selections. As pests and diseases spread into areas which were previously inhospitable to them, plant material with adequate resistances must be accessible. Grapevine viruses have always been a part of the eco-physiology of *Vitis* species, but never has plant material been as easily transported as in the 21st C., or the grapevine as widely and rapidly planted as it is now. As such, the need for robust screening and breeding processes is exceptionally important for multiple reasons:

> *"Nearly 60 different documented viruses infect grapes worldwide, which is far greater than the number of viruses documented in any other single perennial crop… Some viruses are spread by insect vectors and others by soil-inhabiting nematode vectors. Since wine grapes are propagated by vegetative cuttings to maintain varietal integrity and clonal identity (true-to-type), all these viruses can be spread from place to place through the distribution of infected vegetative cuttings"* (Washington State University, 2016, p. 2).

Many of these viruses, most notably the Grapevine Leafroll-associated Viruses (GLRaVs) and a relative newcomer, Grapevine Red Blotch virus (GRBV), have infected Ontario vineyards with disastrous effects. They have already necessitated large vine rip outs in France, Italy, South

Africa and Australia. Breeding programs are intrinsic to an industry's ability to withstand both pathogenic and climatic threats.

It is no coincidence that many of the same research institutions and universities which are addressing climate change are also home to grapevine breeding programs. At Montpellier SupAgro, researchers have found that nighttime water loss through transpiration in grapevines is highly dependent on cultivar. This little understood phenomenon will be critical in the perilously low moisture conditions that are forecast to worsen in southern Europe, and has led researchers to explore the potential for long-forgotten indigenous grape varieties in the Mediterranean region which may have natural drought tolerance and heat resistance (Lallemand, 2018).

Geisenheim University in Germany focuses on breeding new rootstocks and better clones of traditional German varieties, as well as exploring the potential of wild vine species genetics. I visited a research block within an 11 ha parcel allocated to this breeding program that had over 1,000 different clones of the Riesling cultivar alone (*See Figure 4*). Rootstock characteristics that are sought include phylloxera aphid resistance, graft compatibility, and soil/site condition suitability, while scion selection trials are guided by horticultural aptitudes including temperature and moisture thresholds. An experimental wine cellar allows breeders to test the marketability of the wines produced from propagation trials. Plant pathogens are closely screened using analytic methods such as ELISA (enzyme-linked immuno-sorbent assay) to ensure that the planting stock remains clean (Schmid, 2018).

Figure 4. **Geisenheim University, Germany. Breeding Blocks and Pilot Fermenters (G. Robertson, 2018)**

In the USA, Cornell and the University of California at Davis (UC Davis) have partnered in the National Clean Plant Network Centers to propagate, maintain, and distribute healthy grapevine budwood to the American industry. With the help of Cornell, New York State has a virus testing and certification program and are helping private nurseries establish clean mother blocks (Vanden Heuvel, 2018). I was introduced to the VitisGen2 project which aims to speed up the breeding process by identifying genes that relate to desirable traits for growers and consumers alike such as high and low temperature tolerances and disease resistance and fruit flavour qualities. This information will help guide nurseries towards propagating the best possible plant material in a way that has traditionally not been possible. Connecting wine quality to vine quality directly seemed to me to be a really progressive step. The connection between high quality cultivar and clonal selection is something that could be demonstrated and studied in Ontario viticulture programs with the help and collaboration of local nurseries and growers, by integrating viticulture courses with sensory analysis components.

In California, I was able to visit a variety of facilities and labs connected to the Viticulture and Enology program at UC Davis with my host, Dr. Karen Block. While their clean-stock mother blocks are generally off-limits to the public, I learned about Dr. Andy Walker's breeding program that targets plants with resistance to phylloxera, drought, salinity, nematodes, fanleaf degeneration, phylloxera, Pierce's disease, mildews, and tolerance to salinity and drought – all

current and future threats to the California wine industry. These selections are guided by DNA marker analysis and genetic mapping in an effort to characterize resistance genes. Further to this, UC Davis is central to the California Grapevine Registration & Certification Program (CGRCP) which is administered by the California State Department of Food and Agriculture (CDFA). Davis operates what is known as the "Foundation" mother block which endeavors to maintain a clean source of planting material for the industry, where vines are visually inspected twice a year for disease symptoms and tested by ELISA every three years. These protocols are in place in an effort to eliminate Leafroll and Red Blotch viruses as well as Fanleaf, Corkybark, Stempitting, Fleck and other diseases in an ongoing way (Block, 2018). The Ontario wine industry has been accessing certified virus-free material from nurseries certified under this program for the last few years, but they are expensive with shipping and customs costs and this represents only a small proportion of vines being planted in the Province at this time. It is clear that we will need a domestic source of clean material to ensure long term success.

I encountered a historically strong but forward-looking breeding program at Changins Wine School, a university in Switzerland, hosted by Dr. Roland Riesen, Professor of Oenology. Research at Changins has been directed towards the selection of new, unique *Vitis vinifera* crossings such as Gamaret, a crossing between the French Gamay Noir grape and the German Reichensteiner that is early ripening and resistant to fungus. Since the mid-1990s the program has honed in on fungal resistance by crossing *Vitis vinifera* with North American and Asian species, resulting in the red grape Divico and the white grape Divona, both of which are said to have high wine quality potential. Clonal improvements to local grapes such as Chasselas, such as concentrating the naturally occurring organic acids to address climate warming and maintain oenological quality, are also being conducted. Also in response to climate change, a collection of over 1600 clones of 17 vine varieties has been established in multiple mother blocks in diverse sites throughout the country to preserve the genetic diversity and continuity of these cultivars (Riesen, 2018).

While the primary focus of breeding programs in Europe and the United States relate for the most part to popular international varieties that are easily marketable in a global context such as Cabernet Sauvignon, Pinot Noir and Chardonnay, I observed less conventional crossings in Sweden and Norway (*See Figure 5*). Dr. Hans J Rosenfeld, a breeder in Norway, has been working on interspecific hybrid vines that are fungus resistant and adapted to cool-to-cold climates. His own parameters for success with these include the ability to ripen "ultra-early" at 600-800 Growing Degree Days°C (GDD) - most *V. vinifera* need a minimum of 1000-1200GDD - that they have loose clusters and thick skins to resist fungal bunch rots, that they have low temperature tolerances to at least -20°C, and that the wine quality of the grapes approximate noble *Vitis vinifera* wines, which is often a stumbling block when *vinifera* is crossed with North American or Asian grapevine species (Rosenfeld, 2018).

Figure 5. **Breeding Blocks in Denmark; Dr. Richard Smart, Viticulture Consultant (G. Robertson, 2018)**

At the same conference I was able to speak with Anja Antes, owner of Antes Weinbau Service GmbH, a grapevine nursery in Germany. She has been specializing in the propagation of modern crossings that are fungus resistant and early-ripening, such as Regent, Rondo and Solaris, Johanniter, Cabernet Cortis, and Muscaris, many of which I was able to observe performing admirably in the cool, damp, short-seasoned vineyards of Denmark and Sweden with as few as 2-3 organic fungicide applications per year. Her company has also partnered with

federal agencies and universities in Germany on something called the “BigGrape” project. This project has a goal of developing an easy, reliable, non-destructive method of identifying presymptomatic nursery vines with untreatable diseases such as Esca, phytoplasmas and viruses, using a hyper-spectral camera system to analyze the UV-VIS-NIR spectrum Grapevine Leafroll-associated viruses. The work endeavors to associate specific disorders with spectral signatures which will be developed after several years of data have been collected.

As Canadian viticulturalists endeavor to expand plantings beyond the traditional Viticultural Areas and into colder regions – or if growers in the existing Viticultural Areas simply want to explore more robust planting options – some of these hybrid families being bred in Northern Europe may offer the promise of reliable vine performance, good yields, high wine quality and economic sustainability.

Beyond simply knowing which cultivars grow best in which areas, growers in Ontario must have full confidence that the planting stock available for purchase locally is robust and pathogen-free. Nursery propagation processes are critical to buffering the industry against major disruptions. The long term financial commitment of planting grapes is evident in the fact that returns are delayed for at least three years after planting before a crop may be harvested. Given this, we typically endeavor to plant vineyards that will be productive and commercially viable for at least a generation, so the question of which grapes will be suitable in not just 3 years but in 10, 20 or 30 years becomes critical, and the planting of weak or infected material is potentially disastrous for growers and their families.

The Canadian industry has been forced to reckon with this reality in the last few years with a high incidence of Leafroll and Red Blotch viruses appearing in many vineyards planted in the last two decades. An organized response has emerged in the last two years in the form of the Canadian Grapevine Certification network. This not-for-profit industry agency has a mandate to create a certification process for virus-tested, pathogen-free grapevines, and to promote the use of such certified vines in Canada’s Viticultural Areas. This project is still in its early days, but has secured funding for an Interim Verification Program that will conduct screening of mother blocks in a way that will limit the risk of propagating the most prevalent virus strains. However, to date, no certified virus-free material is available.

Educating the next generation of vineyard workers in the perils of pathogen infection and spread in the Canadian industry is a key part of helping the industry as a whole address this threat. Academic programs in Ontario must ensure that they include lessons in traditional symptomatic or biological identification methods, in modern analytic and screening techniques and diagnostic technology such as ELISA and PCR, as well as a thorough understanding of grafting and nursery processes. These same lessons must be captured and interpreted in easily understood language and repeatedly broadcast to the grape growing community at large as it

will take a critical mass of stakeholders with a common goal of greatly limiting virus spread to get ahead of the problem.

2.2 The Land Problem: Does Everybody Want to Live in Wine Country?

The Greater Golden Horseshoe, which is bookended by the Niagara wine region to the south and Prince Edward County wine region to the north, is Canada's most populated and fastest-growing region. One in three new immigrants to the country chooses to settle in this area, and many Canadians move from other regions to this area for employment (Ontario Federation of Agriculture and Environmental Defense, 2015). A population which stood at 8.7 million in 2011 is forecast to hit 13.5 million by 2041 by some projections (Ontario Federation of Agriculture and Environmental Defense, 2015). Rapid growth has already put pressure on infrastructure, transit, the environment and farmland which will continue to be exacerbated by further growth and development. Total farmland area in Niagara decreased by 2.1% or 4,660 acres from 222,911 acres in 2011 to 218,251 acres in 2016; the total number of farms in the region dropped from 2,014 to 1,837 in this same period (Niagara Region, 2018). Demand for grape land in these small VA's has driven prices up dramatically in a short period of time: "The growth of these industries [grape/wine and tourism] since the early 90's has created an upswing effect on agricultural land values, more specifically, vineyard land values in Niagara."(Chew, 2017). Offshore investments have compounded domestic pricing issues as well.

Even as the real estate market has grown in value, the actual GDP impact from agriculture has also grown from $1.22B to $1.41B from 2011 to 2016, as have export values, and employment numbers have gone up from 17,227 to 19,892 ("Niagara Agricultural Profile", 2018). Much of this can be explained by the proliferation of wine grape plantings, a high value crop that requires a lot of labour. The amount of prime agricultural land converted to non-farm land uses through official plan amendments (OPA's) has been quantified for the Niagara Region by the Ontario Professional Planners Institute in s study from 2000-2014 . It indicates that 42 OPA's converted 2,035 ha of prime agricultural land to urban or rural development or non-farm uses. It is clear that there are competing interests for land use which has already had the effect of driving land prices up, and of creating uneasy relationships between farmers in different agricultural sectors competing for the same land, and between farms and non-agricultural residents and businesses. It is very common for farmers in Ontario's wine regions to receive noise or odour nuisance complaints from commercial or residential neighbours related to bird control, cold weather mitigation, soil fertilization or other common activities even when best practices and bylaws are followed in full, a symptom of population density and divergent understanding, values and interests.

While the availability and price of land is evidently problematic for grape growers and wine producers in Ontario, observations from my Nuffield visits suggest that potential solutions exist. These include using existing land more efficiently and lowering input costs, achieving high yields from this land while maintaining fruit quality standards, ensuring that Ontario grapes and wine are of sufficient quality to command sustainably high, "premium" pricing on the domestic and global wine markets, and discovering ways to expand wine grape plantings outside of the current Viticultural Areas and into new, less population-dense, less expensive regions. Intrinsic to this discussion of land use is the notion of developing a truly sustainable grape and wine industry in Ontario that aligns with the three conventional pillars of corporate sustainability: economic, environmental and social. It is apparent that the social license to operate of grape growers and winemakers is contingent on an understanding of and adherence to these three pillars in relation to how agricultural land is procured and worked in wine country, in ways that echo dynamics playing out in other wine regions which I visited.

2.2.i Be a Good Neighbour: Sustainable Viticulture

In the same way that climate change science represents a vital and well-funded topic of study for researchers, professors and students at viticulture institutions all over the world in 2019, the topic of "sustainability" in viticulture came up again and again in my Nuffield travels. The more precisely defined practice of "organic" viticulture was often addressed, and the even more difficult and polarizing system of "biodynamics" made an occasional appearance, though it often seems to run counter to research methodologies employed on post-secondary campuses. It became apparent that any discussion of land constraints requires consideration of sustainable farming and business operations.

I met Greg V. Jones at the XIIth international Terroir Congress in June 2018. While his conference talk was quite granular, referencing a single vineyard study in Oregon where he is Director of the Evenstad Center for Wine Education at Linfield College, he referenced survey work in sustainability trends in global wine growing that he'd done previously. A total of 1,305 surveys were submitted from over 25 countries with responses coming from primary producers as well as academics, researchers, industry suppliers and political or regulatory organizations associated with the industry. A clear majority of 89% answered the question "Do you think that it is important for your company to follow a sustainable development model?" in the affirmative, which is consistent with other surveys conducted in the last two decades. It was noted that respondents considered economic sustainability to be the number one priority of their business, while things like "integrating energy saving practices," "reducing pollutant product usage," "reducing waste and sewage production," and "integrating water saving practices" each rated highly as priorities for improving sustainable business practices. Notably,

all of these reflect the environmental aspect of sustainability specifically, which seems to be the most visible aspect for producers and consumers alike. Lower priority was assigned to actions relating to social sustainability such as “minimizing acoustic, olfactive, and visual pollution” and “supporting your local community” (Jones, 2011).

The Wine Studies Major at Linfield College reflects Dr. Jones’ research work in both sustainability and climate issues, offering an interdisciplinary and very flexible approach to a degree program with course offerings from multiple departments collaborating together including the faculties of the wine sciences, environmental sciences, biology, business and media and communications. The program is explicit in its focus on not only the viticultural, oenological and sensory sciences, but also more broadly in imparting an understanding of environmental and corporate sustainability and the cultural and social significance of wine beverage products and the wine industry at large.

Down the Pacific coast from the State of Oregon, The University of California at Davis has also embraced the notion of sustainability in its programming and research. This is manifest on their Davis campus in the form of the Jess S. Jackson Sustainable Winery Building, an 8,500 ft2 zero-carbon, teaching and research facility attached to a cluster of buildings known as the Mondavi Institute for Wine and Food Sciences, which is also an active trial in eco-friendly engineering and construction practices (*See Figure 6*). The $4 million building is a model of energy efficiency and is designed to passively heat and cool itself, never dropping below 10°C or rising above 27°C in even the most extreme ambient temperatures. A venting and fan system which circulates warm daytime or cool nighttime air down to floor level according to need is backed up by a geothermal system which can heat or cool the concrete foundation slab. Rain water is collected and filtered to the point that it can be used in all normal industrial cleaning processes, and 90% of the water and chemicals used in cleaning in the winery building are captured and purified for reuse. When I visited, a system for capturing carbon dioxide from active fermentations and converting it into calcium carbonate with almost zero emissions waste was being designed, though this had not yet been implemented. Plans to back up power availability for equipment and infrastructure with solar panels and hydrogen fuel cells were also in the works (Block, 2018). A variety of research work at Davis has investigated topics such as cover cropping in vineyards to promote soil conservation and rejuvenation, biodiversity conservation practices, input and waste quantification techniques and the impact of social networks on sustainable practices in grape growing in the California industry. UC Davis has also partnered with the California Sustainable Winegrowing Alliance on projects and workshops through their Extension program.

Figure 6. **Jess S. Jackson Sustainable Winery at University of California at Davis (G. Robertson, 2018)**

In the Eastern United States, the Cornell Cooperative Extension has partnered with the New York Department of Agriculture and Market's Soil and Water Conservation Committee on something called the Sustainable Wine Initiative. This project endeavors to promote and expand sustainable production practices in the grape and wine industry in that State through a self-assessment activity to identify potential areas for improvement with regards to sustainability, followed by the development of an action plan. The self-assessment workbook that was developed in this collaboration addresses specific production practices commonly employed by growers to manage soil, canopy growth, and pests, and provides model examples

so that growers can compare their own practices to recommended baselines to improve their own sustainability (Vanden Heuvel, 2018).

Within the degree program at Cornell, Dr. Justine Vanden Heuvel and other faculty members developed, in 2010, what they say was the first undergraduate course in the United States to focus specifically on sustainability issues and alternate growing practices including organic production. The two-semester "Sustainability and Organic Grape and Wine Production" course is structured around critical reading and discussion of sustainability topics and labs in which students experiment with specific methodologies such as analysis of environmental footprint of specific agricultural activities, soil nutrition, pest and disease management and wastewater analysis and treatment. A grant allowed the 2010 class to plant an organic vineyard at Cornell's Ithaka, New York, campus, which allowed students and faculty to begin to identify cultivars which might be most suitable for organic production in the Upstate New York climate based on innate disease resistance and cold hardiness. The course is a direct result of data suggesting that the number of certified organic grape growers and wineries is on the rise globally, and therefore that students will very likely encounter organic production methods when they embark on their careers in the global wine industry.

The course is careful to address the integration of grape growing and processing as a complete value chain. Given the prevalence of organic and biodynamic vineyard and winery operations in Ontario and the global wine world in general – as of 2017, 5,835 vineyards (or 10%) of France's vineyards were certified organic or in conversion - some programming in these practices may be expected to play a role in classrooms in Ontario viticulture schools. While certified organic production is not, and need not be, an end-goal for the majority of Ontario's growers, there are nonetheless lessons in sustainable viticulture which can be borrowed from it. This is especially true as the regulatory environment in Ontario horticulture seems to be moving towards shortening the available pesticide list, therefore alternative methods of managing weeds, insects and disease must be carefully considered.

In the north of Italy in Trentino-Alto Adige – a region defined in many ways by pristine wilderness and natural beauty, and where the people were often explicitly eco-conscious - at the Edmund Mach Foundation at the Istituto Agrario di San Michele all'Adige, I found a program with a distinct interest in organic viticulture (*See Figure 7*). The teaching winery at the foundation complex, which supports the education and training programs at the institute, produces a line of wines made with the help of students from their Navicello block which is certified organic. Organic regulations are followed and documented in both the vineyard and winery to achieve this certification. The Research and Innovation department at the Foundation contains what is called the Sustainable Resources and Bioresources Department which conducts research to better understand and promote the sustainable use of natural and agricultural

ecosystems and develop applied technologies and low impact agricultural processes to achieve this end.

In an interesting example of industry collaboration, the university also partnered with one of the largest wine producers in the Alto Adige region, the Lunelli family-owned Ferrari Winery and Tenute Lunelli group, to develop a set of organic and sustainability standards which they call “Vigneto Ferrari.” This program is certified by the well-known Italian “CSQA” agri-food and biotechnology certifying body. Interestingly, the standards have re-introduced traditional fertilization and soil management techniques such as cover cropping and composting systems and has eliminated the use of synthetic pesticides and chemical fertilizers. More than 500 local grape suppliers to this large conglomerate processor adhere to these standards, and the protocols developed by the Foundation seem to be effective and useful given the strong adoption. In the name of expanding our own understanding of organic practices in Ontario, a partnership between Brock University or Niagara College and one or more of the commercial organic operators in the region would be useful to examine best practices for our climate and soils, and perhaps help make the case for the expansion of these practices with the potential to mitigate the use of specific chemical groups with collateral damage on indigenous insect populations, for example (Arthur, 2019).

Figure 7. **Istituto Agrario di San Michele all'Adige, Alto Adige, Italy (G. Robertson, 2018)**

A little further South in Italy, Dr. Milena Lambri toured me through the Università Cattolica del Sacro Cuore oenology cluster in the town of Piacenza. This city lies in the centrally located food belt of Emilia-Romagna and has strong food science and agricultural sciences departments. The viticulture and wine sciences department offer undergraduate and graduate programs and is quite outward looking, finding research and training partners in companies in several different Italian wine regions with diverse soil and climate types. Viticulture research specializations at the school center on vine physiology trials and the development of canopy management techniques to improve fruit quality and also to explicitly lead to sustainable approaches to pest and disease control and water management techniques. Curriculum within the undergraduate and Master's programs juxtaposes traditional growing techniques with precision viticulture methods to address vineyard variability and yields, to make the most efficient use out of land being farmed, and seminars are offered to both students and external industry members on the sustainable use of pesticides (Lambri, 2018).

The same campus that houses the Oenology and Viticulture training programs at Changins in Switzerland is also home to Agroscope, a research division associated with the Swiss Federal Office for Agriculture. Environmental protection in relation to agricultural activities and sustainable food production are mandated within the operation of this department. From what

Dr. Riesen described, a cultural significance is attached to the concept of sustainability in Switzerland and so curriculum at Changins addresses sustainability in the wine sector in a variety of ways, including energy and resource consumption, waste and by-products management, soil microbiomes, winery eco-design. Ongoing research at Changins includes a project called “Biodyn” which endeavors to understand the impact of biodynamic preparations on vine and berry growth and development, vineyard biodiversity and wine quality, a project called “BiopestiSol II” which studies the effect of specific biopesticides on soil microbial populations and distributions and “NoGlyphos” which is studying alternatives to glyphosate for sustainable management of weeds in viticulture (Riesen, 2018).

At the VitiNord Conference in Denmark-Sweden, Dr. Vassileios Varelas, a consultant in the Swedish industry, gave a talk titled “Sustainable oenology and viticulture: new strategies and trends in wine production” which surveyed the current state of sustainability initiatives in global viticulture. He pointed to strong industry initiatives in California, New Zealand, Australia, Chile and Ontario, Canada. He also highlighted the most significant technologies and practices being used to achieve these sustainability goals. These include organics and biodynamics certifications, precision viticulture tools to best assess and manage water, soil and nutrient status in vineyards to apply products in targeted ways, site selection and vineyard design principles, new, efficient spray application technology, and using appropriate cultivar, clone and rootstock selections to match environmental conditions and facilitate management operations down the line. He also addressed packaging and distribution technologies and winery by-products processing and use (Varelas, 2018).

While concepts in sustainable viticulture (with incidental mention of aspects of organic and biodynamic processes) already form a part of both the Niagara College and Brock University programs, it can be expected that concepts in sustainable operations and corporate and social responsibility will grow in importance. Course material can be expected to include precise input, output and by-product metrics and documentation, water and energy conservation and efficiencies, waste and by-products capture and management, pesticide use best practices within overarching Integrated Pest Management strategies, conservation and promotion of ecological biodiversity and ecosystem management, and environmentally-minded value-chain assessments and decision-making.

Some members of the Ontario wine industry have participated in a sustainability certification program called “Sustainable Winemaking Ontario” (“Ontario Craft Wineries”, 2017). Accredited membership in this program which involves both self-assessments and a third-party audit, is quite small relative to the total number of operations in the Province. A partnership between educational institutions such as Brock or Niagara College and the program organizers to assess any apparent barriers to adoption and avenues for growth could be worthwhile. Attaching students and faculty resources to these programs might help focus and improve

them, while at the same time providing students the opportunity to gain frontline experience of a credible sustainability initiative.

2.2.ii Addressing Land Issues through Technical Efficiency and Productivity

While the cool, damp vineyards and short growing season in Denmark and Sweden are likely not destined to produce extremely high yields, the rich soils and ample heat of California's San Joaquin Valley are capable of producing exceedingly high tonnage. Several processors have set up enormous processing facilities in this region for this very reason. It is evident that one way of addressing high land costs is to make that land more productive while also spending less money farming it, and Fresno State University has built an experimental vineyard block around just this concept.

Dr. Sonet Van Zyl, Associate Professor of Viticulture drove me through a 19-acre vineyard block, planted in 2013 to the French Colombard variety, that was designed to demonstrate cutting edge vineyard mechanization techniques (*See Figure 8*). The block was planted with financial assistance from West Coast Grape Farming/Bronco Wine Co., a large company that is active in a part of the State where grape prices are low, necessitating high yields. Donations from local grape industry suppliers for vine material, trellis and irrigation systems as well as some of the equipment needed for the mechanization trials also allowed the project to succeed. The goal of the project is to achieve yields of up to 20 tons per acre while maintaining fruit quality that adheres to processing standards set by the industry - all while farming the block 100% by machine, with no hand labour whatsoever, which is by nature slow and expensive.

The training system was designed as a single high-wire trellis with no line-posts to interfere with equipment during operations such as pruning, hedging and shoot and leaf removal. Vine vigor is managed by irrigation and fertilization. The Department of Viticulture and Enology at Fresno State offers a semester-long mechanized viticulture course that allows students to take advantage of the research block and the vineyard equipment associated with it. The field trials conducted up to this point have suggested that relative to hand-labor operations, a fully mechanized grape farming system is capable of achieving large financial savings while maintaining vine balance and higher yields and quality in some cases (Van Zyl, 2018).

Figure 8. **Fresno State University, California, Mechanically Farmed Research Block** (G. Robertson, 2018)

In a similar effort to reduce expensive hand labour in the vineyard, Geisenheim University has conducted trials into what is known as “minimal pruning” in the Rheingau region of Germany, with students in the undergraduate program processing the fruit from these trials into wines. Dormant pruning, wherein much of last year’s tissue growth is removed, remains a challenge for currently available vineyard equipment to perform successfully given the precision of the work required, and is also the single most time consuming and expensive hand labour operation performed annually by grape growers. Minimal pruning systems use tractor-mounted box hedgers to gradually reduce both dormant and active growing season growth in a way that allows the vine to balance vegetative and reproductive growth over time. While this technique has shown promise in some regions in Australia and Italy, the ultimate success is highly dependent on a variety of factors such as vine type, climate type, water and fertility status of soils, and regulatory factors such as yield limitations in European wine regions. As such, Geisenheim is conducting work to understand how this technique may be implemented in cool climate wine growing regions and to understand the long-term effects of such mechanized crop management on fruit yield, vine phenology and wine quality.

A group of universities, including Cornell, UC Davis (where I heard of the initiative), Penn State and Carnegie Mellon, and government agencies including the US Department of Agriculture (USDA) and French National Research Institute of Sciences and Technology for Environment and Agriculture (IRSTEA) are involved in something called the “Efficient Vineyard Project” with a goal of helping the wine industry adopt new management strategies and technologies that will improve overall production efficiency. This effort can generally be categorized under the umbrella term “Precision Viticulture” and specifically endeavors to develop remote sensing and

automation solutions for measuring vineyard soil, canopy, and crop characteristics in a way that allows for high-resolution spatial vineyard mapping as an overarching management tool. Researchers are looking at existing sensor technologies to identify technology gaps with a mind to developing novel sensor systems for data collection. Data interpretation and mapping systems are also being developed to allow for application of a variable-rate crop load management systems on a commercial scale, and ultimately to develop end-user tools for growers. Ultimately, such tools will help growers farm large acreages while using material and labour inputs in an informed, targeted and efficient way.

It is apparent that the technologies and skills associated with "Precision Viticulture" including remote sensing, data systems management, GPS locating and GIS mapping is now a requisite part of undergraduate programs in classrooms at Cornell, UC Davis, Stellenbosch University, Fresno State, Elsenberg College, California Polytechnic, the University of Bordeaux, Changins, and more. Reinforcing the importance of these fields of study further, Christer Johansson gave a talk entitled "Launch of IoT and Artificial intelligence to increase the competitiveness in Swedish fruit and wine production" at the Vitinord conference. He emphasized that technology such as this can help new, up and coming winegrowing regions in marginal climates compete with more established commercial grape and wine producing regions. Even enormous, established regions such as California recognize the need to produce wines at competitive prices. At the Unified Grape and Wine Symposium I was able to speak with Dr. Keith Striegler, a well-known academic and consultant in the American industry, who indicated that higher yields, better grapes and lower costs are necessary to a large part of the American industry given international competition from countries with lower labour costs and more labour availability (Striegler, 2018). Mechanization and precision viticulture techniques are now key tools for any producer looking to compete on the world market, including in Ontario. Ontario viticulture programs should look at bringing in faculty experts from other departments within their schools to incorporate material pertaining to Precision Viticulture into existing curriculum.

Mechanization has already helped Ontario's grape growers farm their land more efficiently, though near or total mechanization as observed at Fresno State has not been trialed in the province, as our small industry has fewer resources to access the capital required for such a project. As such, there is likely an opportunity for local research institutions to investigate the feasibility of such a machine-driven system in our region. A minimal pruning system has been trialed by a single grower in the Niagara Peninsula with promising, but imperfect, results and also bears further investigation. As noted above, the vineyard worker of the near future will need to have a large capacity to operate and maintain numerous types of mechanical equipment and the software that runs these machines.

2.2.iii Aim High: Looking Towards Premiumization and Specialization

While reducing input costs and increasing yields can affect a grower's bottom line significantly when purchasing and planting on expensive land, the production of high, or "premium," quality grapes that command a suitably high price on the market as grapes and wine can also offset land costs. Grape prices in Ontario are set by the Grape Growers of Ontario (GGO), an independent organization funded by grape growers themselves which promotes the grape and wine industry in the Province, acting under the authority of the Ontario Farm Products Marketing Act (Grape Growers of Ontario, 2017). Payment is dictated by tonnage and sugar levels on a sliding scale – higher sugars result in higher prices - but premiums are paid in many cases for fruit from desirable vineyard sites that have historically produced great wines, or for management practices known to result in higher quality fruit and wine such as crop thinning, exposing clusters through detailed leaf removal, stringent manual shoot placement and other techniques. These practices may incur higher input costs including more labour hours, but justify significantly higher price points relative to wines produced from less well-tended vineyards.

Another way to leverage existing vineyard acreage is to plant unique cultivars or make unique styles of wine in order to carve out a market niche that is distinct from other producers. This may also help a grower attain premium price points on products. A grower might, for example, plant Spanish or Italian cultivars such as Tempranillo or Nebbiolo that are rare in our climate, and work hard to ensure their viability in the vineyard. While almost all wineries in the same region will offer Cabernet Franc or Pinot Noir wines to consumers, this producer can become a destination for savvy consumers who are happy to pay a premium for unique and rare wines. An example of this "specialization" phenomenon is already evident in Ontario in the production of Icewine, where grapes are hung on the vine long after the first frost has hit and the leaves have fallen, to be picked and pressed while still frozen and transformed into the sweet dessert wine. The production of this style of wine is simply not possible in the majority of the world's grape growing regions which don't usually get the same sub-zero temperatures that we do in Ontario. Icewines command very high price points relative to most other wine styles given their distinct flavour profile and relative scarcity. Finding new and innovative avenues towards premiumization or specialization offers potential for growers to succeed in competitive global markets. These observations were informed by several stops in my travels where I was able to visit training institutions with curricula that directly helped to support and shape premium or specialized local wine industries.

The Lycée Viticole de Beaune is an applied training college in the city of Beaune in the Burgundy wine region of France. This region is renowned for the centuries-old production of high quality wines made from the Chardonnay and Pinot Noir grape varieties which often sell for stratospheric prices. The institute offers several training options including a 2-year Advanced

Agricultural Technician Diploma in Viticulture and Oenology. At its core, this diploma supports local wineries and vineyards by providing graduates with skills that apply directly to the production of the short list of grapes grown in the area. Agricultural and processing regulations in this region are extremely stringent in order to protect and standardize the high quality of wine products, so the curriculum at the Lycée is quite specific to this locality and oriented towards practical application of viticultural and oenological principles. There is a sense of history and legacy at the school, and many students come directly from local winegrowing families, training to follow in the footsteps of the many generations of grape growers who have worked the same family plots. Best practices in grape growing are not being discovered for the first time as they are in Canadian regions, they have evolved since before the first written record of the Pinot Noir grape in the region in 1375 (Robinson, Harding & Vouillamoz 2012).

I visited campus facilities including classrooms, sensory labs, the teaching winery (or "Domaine") and some of the 19 hectares of vineyards owned and operated by the school, hosted by winemaker and instructor, Christophe Briotet in July of 2018 (*See Figure 9*). These vineyards, which students use in the course of their training, are some of the most highly prized in the region, known as "Première Crus" or "First Growths." The vineyard holdings and Domaine have no government funding subsidies so they must make and sell wine as any other private business would. While there is financial pressure to ensure healthy sales, this allows for students to participate in real experiential learning opportunities to reinforce theoretical work in the classroom. Students engage in all aspects of the production cycle from vine management to harvest to vinification, on to packaging, marketing and sales. The wines produced with student collaboration regularly win awards at international wine competitions, which Christophe suggested was important as a concrete demonstration of applied knowledge resulting in top tier products. The school has a tasting room where wines may be purchased by locals and tourists year-round, and pricing is on par with the regional standard, which is high relative to Chardonnay or Pinot Noir wines made in Canada and most other winegrowing regions (Briotet, 2018). Some Ontario producers have adopted a "Premium" model that emphasizes a portfolio of wines made from small plots of estate-controlled land farmed with the utmost care and attention, and are able to remain viable as small businesses in this way, but the majority of operations feel the need to compete at entry- and mid-level price points as well. Education and training programs in the province must be able to provide insight into production practices that achieve products conforming to all tiers and price points, but should consider it a priority to model excellence in grape growing in a way that emulates the most quality-minded producers in the industry, in my own opinion.

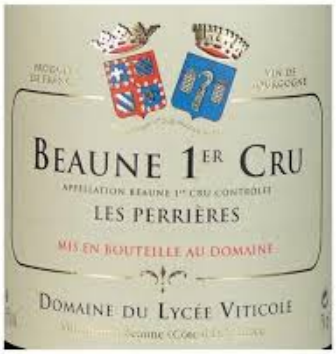


***Figure 9*. Facilities including Première Cru Vineyards at the Lycée Viticole de Beaune (G. Robertson, 2018)**

I discovered a similar training model in completely different environmental and viticultural circumstances in Conegliano in the Veneto region of northern Italy. A lush and hilly wine region, known as "Prosecco," comprising approximately 20,000ha of vineyards between the towns of Conegliano and Valdobbiadene currently produces the most popular sparkling wine on the planet, selling more bottles per year than even its famous French cousin, Champagne. These wines are predominately made from three clones of an indigenous grape cultivar known as "Glera," using very specific processing technology including fermentation in isobaric, or "closed pressure", tanks to achieve their desired carbonation levels and flavour profile. While this grape has occasionally been transplanted to other countries, and the technology to make sparkling wines in this way is widely available, no wine producing regions have achieved quite the same style profile or nearly the same success. Just as The Lycée Viticole de Beaune supports its own industry, The School of Viticulture and Enology ("Scuola Enologica G. B. CERLETTI") of Conegliano, associated with the University of Padua, trains more than 1,200 students annually in a variety of programs running the gamut from 3-year technical diplomas to 5-year Agricultural Engineer bachelors to graduate degrees – all with a strong emphasis on local production methods relevant to the production of Prosecco wines.

This was Italy's first enological school, and its inauguration in 1876 coincides with the rapid growth of Prosecco wines. I was able to visit its campus which includes the "Experimental Institute of Viticulture" and "Regional Center of Viticulture," collaborative research institutes with the Regional and Provincial governments of Veneto and Treviso, and a commercial teaching winery and distillery ("el'Enoteca"), alongside conventional classrooms and labs. While there were translation issues during the tour – my Italian is distinctly lacking - what was apparent was that the teaching vineyards and winery resources were dedicated almost exclusively to the cultivation of the Glera grape and the production of sparkling wines made in the pressure tank method. Researchers and faculty at the school have taken a lead role in helping the local industry discover and define its best growing sites, or "Rives." This project is intended to help local growers plant the most appropriate clones in the best soils and topography to achieve maximum potential quality in their regional wines. It was apparent that the school was an integral part of the local wine industry in both research and instructional capacities.

Figure 10. **Facilities including Vineyard and Teaching Winery with Charmat Pressure Tanks at the Scuola Enologica, Conegliano, Italy (G. Robertson, 2018)**

While Prosecco wines are an undeniable global consumption trend, Champagne has never really been out of fashion since its bottle-fermented sparkling wines became a domestic and export industry in the north of France in the 16th century. No regional wine style is as clearly defined as a paradigm for quality and desirability on the global market as Champagne is today, though Burgundy is a close contender. Inevitably, yet another viticulture school exists in this region to support the production of what are very regulated, technically-made, process driven wines. I visited the Avize VITI post-secondary institute campus in the famous Côte de Blanc sub-region of Champagne in unseasonably cold March weather. Students were busy learning how to prune dormant grapevines and how to operate the small, specialized tractors that are designed to straddle the tight rows of trellised grape vines that abound in Champagne's roughly 34,000ha of vineyards. The institute offers a number of professional certifications and diplomas relating to viticulture, enology or combinations of both, as well as sales, marketing and wine business certifications. Viticulture training is extremely hands-on involving field experience in the campus winery and 10ha vineyard as well as apprenticeships with local producers, supported by classroom work. The curriculum revolves around local production techniques almost exclusively. The focus is on viticulture related to the seven cultivars that are allowed for use in Champagne production including Chardonnay, Arbane, Petit Meslier and the Pinot family, and the training and trellising styles unique to the region, as well as on learning how to grow grapes under local fertilization and chemical pesticide restrictions. Processing technology and techniques in the teaching winery also follow industry standards for the production of the regional sparkling wines.

There is an important lesson for Ontario schools to ensure that their curriculum mirrors the most important skills and knowledge needed by the local wine industry that they serve and support, and at the same time to help the industry develop new and innovative ways to achieve

their economic and production goals. A premium focus can help offset costs associated with expensive land (and expensive labour, as we shall see in the next section), and specializing in unique wine types or styles can help businesses find a niche within the marketplace and the industry as a whole find a niche in the global market. In both cases, there is an important role for education and training programs in supplying graduates who are versed in relevant skills needed to achieve these aims. A focus on traditional method sparkling wines and on crop-thinned Pinot Noir, Chardonnay, Riesling, Gamay Noir and Cabernet Franc may be advisable for premium production in our regions. Less common aromatic white varieties such as Albarino or Grûner Veltliner and lesser-known reds from cool climate wine producing areas with long histories of viticulture such as the Republic or Georgia, Armenia or Slovenia could provide interesting avenues for specialization.

2.3 The Labour Issues: Availability, Affordability, Suitability

It is anticipated that by 2025, 114,000 agriculture sector jobs will go unfilled in Canada as a whole, and 46,000 will go unfilled in Ontario alone (Canadian Agriculture Human Resource Council, 2016). Forecasts indicate that in this same period overall demand for agricultural labour is expected to go up by 0.5%, while the domestic labour force shrinks due to ageing workers retiring out of the industry and a demographic dwindling of young domestic workers entering the workforce. Approximately 300 fewer young workers per year are expected to enter the agricultural workforce by 2025, while 93,000 workers – a full 27% of the total workforce – are expected to retire. (Canadian Agriculture Human Resource Council, 2016). According to census data, the average age of a farm operator in 2016 in Niagara was 56 years, and farm business succession has been flagged in a report commissioned by the municipality as a major threat to the sustainability of the farming sector (Niagara Region, n.d.). A labour shortage is apparent in the Ontario wine industry specifically. Matthias Oppenlaender, General Manager of Huebel Grape estates, a large contract vineyard operation in Niagara, and Chair of the Grape Growers of Ontario, has noted that:

> *"Vineyard workers [in Ontario] in all capacities are scarce. As the first generation of grape growers and trained vineyard workers look towards retirement, their children aren't staying in agriculture. The demand for skilled field hands, machine operators, scouts and operations managers is high, and there is an expanding need for year-round workers as well as seasonal labour." (Oppenlaender, 2017)*

Further to this, in my capacity as practicum coordinator and instructor at Niagara College, I have a long list of grape growers looking for vineyard workers at all times of year. They are keen to hire student interns or recent graduates: anyone who will show an interest in viticulture, is

willing to be trained, follow instructions and who will work hard. This list gets longer every year. The majority of graduates from the viticulture and oenology programs that do exist in Canada seem to end up on the wine processing side of the business. Much of the difficulty in attracting entrants to the Canadian viticulture industry are common to the agriculture sector in general. In a heavily urbanized society, agricultural employment opportunities are not familiar or understood. Given the small size, youth and localization of the grape wine industry, it is likely even less familiar and accessible than other more traditional agriculture sectors in Canada.

This shortage is occurring at a time when vineyard labour wages have increased. This is partly an effect of the minimum wage in Ontario rising to $14.00/hr in January 2018, which has pushed wages and salaries up in general across the industry, but also as a result of a low supply of labour which has the tendency to push wages upwards. While the labour availability and pricing issue is grave for many growers, potential solutions exist, many of which were explicit or hinted at in my Nuffield visits. Human capital is a key component in the success of any wine industry and labour issues are universal, so wine industries in Europe, the United States, South Africa and beyond are all seeking solutions. These potential solutions included such strategies as attracting new entrants with appropriate skills to meet job requirements, increasing the size of the available labour pool by attracting and retaining more international workers, ensuring that current workers in the industry are equipped through ongoing training programs to evolve alongside changes and disruptions in the sector and are incentivized to stay, and finding alternatives to human labour by adopting new technologies that allow for fewer human labour hours in the vineyard.

2.3.i Decreasing the Need for Labour through Mechanization, Automation and Robotics

As has been observed in section 2.3, above, the adoption of technology related to precision viticulture techniques and the strategic implementation of mechanized equipment in vineyards in general is capable of increasing efficiencies with reference to material and labour inputs. Capital outlay for such technology can be offset by a decrease in expensive human labour hours. While we have seen that precision viticulture is a popular topic in classrooms and labs all over the world, an associated technological disruption of labour systems has already arrived in a variety of forms in commercial vineyards in many of the more developed grape and wine industries in Europe, Australia, the United States, Canada and others. Satellite, digital and wireless technologies are already generating massive amounts of data and sophisticated mechanical equipment such as leaf removers and variable rate sprayers produce massive amounts of work with efficient use of inputs with the help of this data. Some of this technology already falls under the definition of “autonomous” such as sensors mounted on tractors to record canopy, air and soil data automatically, with every pass of the vineyard, as have been

developed within the Efficient Vineyard Project, mentioned above. The optical grape sorting technology developed at Geisenheim University which can separate undesirable materials from healthy fruit much faster than humans ever could is another example of the commercialization of automation in the global grape and wine industry.

Autonomous machines designed to perform specific tasks with a high degree of decision-making skill - or robots - have not yet displaced humans in any significant way in commercial vineyards. That said, some of the prototypes have been so clearly successful in field trials that inevitably, as prices decrease and functionality and ease of operation is proven, they will almost certainly be adopted. As Stavros G. Vougioukas, Associate Professor in the Department of Biological and Agricultural Engineering at the University of California at Davis has said, "[robots] hold the potential to remedy existing and imminent farm labor shortages by increasing or by replacing workers in low-skill, labor-intensive tasks, like manual weeding or harvesting" (Zimmerman, 2019). While I did not encounter any robots directly in the institutional vineyards that I visited in the course of my research (much to my disappointment) several of these projects were mentioned in conversations with a number of my hosts and at conferences.

A prototype for a land-based, autonomous vehicle carrying optical sensors with the ability to record data in the visible, infrared and near-infrared spectra that can be used to identify crop load and canopy issues has been demonstrated in the vineyards of Stellenbosch, South Africa, according to students at Elsenberg College, which I visited in March of 2019. Upon further inquiry, this is a collaboration between the Department of Viticulture and Oenology and the Institute for Wine Biotechnology at Stellenbosch University and the company CSIR (CSIR). Geisenheim University has been involved in developing a similar imaging and yield estimating unit called the "Vinbot" (VINBOT, n.d.). While similar optical technology may be mounted to a tractor or Light Utility Vehicle to log the same data, the software algorithm developed for this robot allows it to perform path planning and obstacle avoidance and therefore removes the need for a human driver. A more sophisticated example of vineyard robotics came up in conversation at the Terroir Congress in Zaragoza. Naïo Technologies in France have endeavored to automate ground management operations further with "Ted", a robot that effectively weeds the under-vine soil in vineyards (Naïo Technologies, n.d.).

My own subsequent research discovered prototypes for vineyard robots from the Echord++ European Union-funded "GRAPE" project (GroundRobot for vineyArd monitoring and ProtEction) which is focusing on land-based autonomous vehicles with a robotic arm that can deploy pheromone dispensers for insect mating disruption in vineyards, for example, as well as carrying data logging sensors. This robotic vehicle uses Global Navigation Satellite Positioning and infrared and laser sensors for its guidance system (Eurecat, 2015). In California, a consortium of researchers from UC Berkeley, UC Davis, and UC Merced are building what is known as the Robot-Assisted Precision Irrigation Delivery (RAPID) system to compensate for a

shortage of human labour when it comes to operating irrigation networks in California. Because there aren't enough workers to adjust the hundreds of emitters that large vineyards in the state require, they are designing rugged, battery-operated robots that move to open and close valves autonomously based on sensor data that is communicated to them (Carpin, Goldberg, & Vougioukas, n.d.). Another Californian company, Vision Robotics Company, has developed a robot pruner to perform the single most onerous and expensive vineyard task in the annual management cycle (Vision Robotics Corporation, 2017). While there are no land-based robots currently available on the commercial market that offer spraying capabilities to the best of my knowledge, there are aerial vehicles (UAVs) currently being used for pesticide and herbicide application. DroneAG, based in the UK, and Yamaha's RMAX both have commercial options available at this time (DroneAG, n.d.) (Yamaha Motor Corporation, 2016).

Most of these examples are still in an experimental phase and are not yet commercially available, though some like Naïo's "Ted" have already been manufactured on a commercial scale and are operating in vineyards around the world. The general opinion by experts is that the grape growing industry will rely on autonomous software systems and robotics to help compensate for labour shortages in vineyards in the near future, and that uptake of these types of technologies will be a critical aspect of remaining competitive for any regional wine industry, particularly in parts of the world where labour is difficult to find and expensive. As a continuation of a well-established theme noted above several times already, the viticulturist of the future in Ontario will have to be familiar with not only traditional growing techniques but also integrate skills from engineering, electronics and computer science disciplines in order to operate these technologies, adapt them for specific uses, troubleshoot errors and maintain equipment in good working order.

2.3.ii Attracting New Entrants to the Industry and Retaining Existing Workers

Digital technologies, automation, robotics and other new technologies are inevitably disrupting current labour systems in complex ways already and will continue to push the grape and wine industry to evolve. These machines will not be replacing vineyard workers completely for some time however. Even as they do begin to supplant field workers, there will remain a need for skilled operators and background support workers to ensure functionality and maintenance of the machines. As such, it remains critical to attract talented people to enter the Ontario wine industry as trained professionals to support the long term health and growth of the sector. The talent pool for these entrants can come either from the Canadian domestic population or from foreign workers coming to Canada to work. The Ontario grape and wine industry currently relies on both, since the domestic agricultural workforce has been steadily dwindling. Many field workers in Ontario vineyards come through federally-regulated Seasonal Agricultural

Workers Programs (SAWP) which currently allow citizens from several Latin American and Caribbean nations to work for 8 months of the year in primary agriculture in Canada (Employment and Social Development Canada, 2019). These programs have their limitations, especially for smaller growers, since the employer is responsible for all transportation and housing of these workers and may not have the resources or on-farm infrastructure to support this. As such, attracting domestic workers into the industry and incentivizing international workers who don't fall under the category of these SAWP programs to come to Ontario to work in viticulture may be seen as a priority for the Ontario grape and wine industry.

Work done by Becky Parker, a 2015 Nuffield Canada Scholar, describes the need to increase exposure of agri-food sector career opportunities to young Canadians to help overcome the forecast labour shortfall (Parker, 2016). Given the low visibility of the viticulture industry in Canada, I also thought it was important to look for ways that educational institutions around the world were attracting students into their programs, and onwards to careers in the grape and wine industry in their local regions. While recruitment efforts are inevitably dependent on operating budgets and human resources with regards to how many high school classrooms can be visited and how many ads can be bought in various media and marketplaces, the messaging of some of the schools that I visited stood out in interesting ways regardless of available resources.

The Colleges and Universities that I visited in California, including UC, Davis, California Polytechnic (CalPoly), Santa Rosa Junior College and Fresno State University (as well as Napa Valley College, La Positas College, Allan Hancock College and Shasta College, which I did not have the opportunity to visit) clearly exist in a competitive market for attracting undergraduates. With so many schools in the state they spend considerable resources publicizing and differentiating their programs in the market. All of these schools had exhibition booths at the Unified Grape and Wine Symposium with faculty and students actively promoting their institutions, programs and research. All of the major universities listed here also seem to ensure a presence at important academic and industry events such as the American Society of Enology and Viticulture National Conference. UC Davis has several advantages relating to its size, historical legacy and reputation for excellence in research as well as access to enviable funding from a variety of public and private sources. It enjoys a far-reaching industry network through its graduates, its research, and Extension outreach work, and touts its high national rankings in the agricultural and plant sciences (amongst other things) in numerous 3rd party reviews (Blouin, 2019).

The CalPoly Wine and Viticulture Program incorporates the College's "Learn by Doing" philosophy in specific ways. Jim Shumate, an enology Lecturer and Pilot Winery Manager, toured me through their classrooms and facilities and elaborated on the ways that students learn the foundations of viticulture, winemaking and wine business (*See Figure 11*).. They work

in their 14-acre teaching vineyard and pilot winery and help to create the CalPoly wine label products that are sold to the public, on top of their normal studies. Funding for a brand new, state-of-the-art facility had just been secured when I visited. The program requires that an industry-related internship or work term be completed, and opportunities for international field studies involving hands-on learning experiences are all promoted to add value to the degree program and, it would seem, to differentiate the program from other more classically academic institutions (Shumate, 2018). Students at the school were enthusiastic about the experiential learning opportunities presented while working in the on-campus vineyard and winery, and indicated that they felt it would help them be more employable upon graduation. An interesting initiative called “The Winemaker Showcase” brings winemakers and industry sponsors to campus for a student-run dinner. This fundraising event supports student learning activities and connects the program to the wide industry and public sphere, in the same way that pouring CalPoly wines at industry events such as wine and food shows does.

Figure 11. California Polytechnic Wine Programs Facilities including Teaching Vineyard and Winery **(G. Robertson, 2018)**

In a somewhat similar way, the Department of Viticulture and Enology at Fresno State University does a great job of bringing their programs to the public, and the public to their programs, by participating in numerous Agriculture Expositions and Conferences that are often outside of grape growing regions and not viticulture-specific, as well as hosting large industry events such as Fresno State Grape Day which offers industry-relevant workshops and networking opportunities, while showcasing current activities and successes of their programs (Van Zyl, 2018).

Several institutions which I visited make much of their experiential learning approaches in a similar manner to CalPoly, including Avize VITI, Elsenberg College in South Africa, and the State Wine and Viticulture Training School of Baden-Wurttemberg in Weinsberg, Germany (or "LVWO.") Many of these schools make sure that they connect this idea of hands-on learning to campus infrastructure facilities including teaching vineyards and wineries, often with retail spaces. There is also a tendency to promote these programs in relation to the desirability of living and studying in "wine country." Institutions such as Santa Rosa Junior College in Sonoma, California, The Lycée Viticole de Beaune and The Wine School at Conegliano all tout the natural beauty and historical and cultural interest of the regions they are located in as part of their recruitment strategy.

When domestic student enrollment is limited by demographics and inter-institutional competition, the option of opening up programs to international students becomes attractive. While many of these international students will return to their home countries to practice viticulture, in some cases they may remain to work in the region in which they studied. While many, or even most, programs accept international applicants, there seems to be a trend in viticulture education to develop programs that specifically target a globally mixed classroom. Often these programs operate as collaborations between institutions in different regions or countries to combine faculty members, specializations and teaching resources and create a stronger program overall that may appeal to a wide swath of international candidates. From what I could see, the opportunity to study in a variety of contexts and the inherent multidisciplinary knowledge exchange between diverse students, teachers and institutions from different geographies and cultures is a selling feature in and of itself to prospective students, some of whom come from places where no wine is produced but who will, upon graduation, enter the workforce in a regional wine industry.

I observed a great example of this when I visited Patrice Lallemand, Director of programming for the Euromaster Vinifera Masters program, in Montpellier, France. The Montpellier SupAgro operates this International Masters program in conjunction with a consortium that includes Geisenheim University, the Universidad Politécnica de Madrid in Spain, two Italian University Consortiums, and the Universities of Lisboa and Porto in Portugal. All students spend a first year of classroom and lab studies together at Montpellier SupAgro with a short course delivered at

the Bordeaux Sciences Agro. The curriculum is delivered in English by a variety of professors from the French institutions as well as from affiliate institutions with instructors traveling to France to deliver specific modules within the course framework. For the second year of the program students select a host institution from within the consortium, but outside of Montpellier and Bordeaux. Their coursework is still delivered in English with the exception of those who choose the Universidad Politécnica de Madrid in which case they must be fluent in Spanish. Part of the second year is devoted to a Masters thesis project which may be researched and written in a third country, inside or outside of Europe, as required by the study topic. The program has been very popular, with over 100 students from 26 nations participating in 2018 when I visited. I am aware of several Canadians who have completed their Masters and who are successfully working in the Canadian wine industry (Lallemand, 2018). The program has received funding from the European Commission's Erasmus+ program for achieving success in the "learning mobility of individuals" and "cooperation for innovation and good practices," stated goals of Erasmus+ (Erasmus+, 2019).

I was made aware of two similar programs when I visited Changins, in Switzerland (Riesen). The "International Vintage Master" program is also a two-year Masters degree in oenology and viticulture, established in 2002 and run through the Ecole Supérieure d'Agriculture (ESA) in Angers (France) with an international consortium that includes Changins, the Pontificia Universidad Católica de Chile (in Chile), Stellenbosch University in South Africa, Universidade de Trás-Os-Montes e Alto Douro in Portugal, Università Cattolica del Sacro Cuore di Piacenza (which I also visited as part of my Nuffield work), Szent István Egyetem in Budapest, Hungary, and the Universidad de Politécnica de Valencia in Spain. Classes are all held in English and studies occur at various institutions in France, Italy and Portugal with short courses and internship opportunities between semesters held in partner schools in other countries. The program endeavors to offer course content that is universally applicable, given the diverse population of students. By all accounts this is a very competitive program to get into and it boasts 347 graduates from 48 different countries – a truly diverse educational experience (International Vintage Master, 2019). The University of Applied Sciences and Arts of Western Switzerland also offers an International Masters Degree that approximates the same model as the Euromaster Vinifera and Vintage Masters programs, though it is considerably smaller (Riesen, 2018).

At a vocational level, the institutional partnership model is evident in the VITEA Vine pruning Erasmus program which I saw advertised at Scuola Enologico Conegliano in Italy. Training and testing for this multi-level program, which is active in France, Italy, Portugal, Spain, Slovenia, Austria and Hungary offers beginner to advanced level certifications in grapevine pruning which are recognized in many European wine regions.

Even in the context of three or four year bachelor degrees or two year diplomas, there is a general trend for universities and technical training institutions to partner together to offer more products to more people, often on multiple campuses. The fact that multiple institutions certify these programs and that they are often internationally recognized is incentive for candidates to apply, as it is seen to expand their career options in the global industry. As an example, the Istituto Agrario di San Michele all'Adige/Edmund Mach Foundation has evolved from an unaccredited training program in the 19th C to a vocational school in viticulture, to a technical high school with Ministerial oversight and accountability, to the point in the 21st C where it can offer multiple certifications including a six-year specialized bachelors program. It has achieved this by partnering with institutions both in Italy, including the University of Trento and University of Udine, and outside of the country with the Fachhochschule of Wiesbaden in Geisenheim. This progression has allowed the school to attract students not just from its own region in Trentino Alto Adige, but from other provinces in Italy and in Germany as well, which has been important to its growth and success at attracting new entrants to its programs, and by extension to the wine industry.

Another way to attract and motivate people who are not at present working in the wine industry is to offer part-time studies which may be in-class or online as part of an institution's "extension" or "outreach" program. The American schools in particular, including Cornell, UC Davis, the University of Virginia and University of Michigan, often have very strong extension offerings with numerous courses offered throughout the year. Participants may be members of the public with a general interest in oenology and viticulture – which may turn into a vocational pathway in the course of their studies – or wine industry professionals looking to upgrade their own knowledge and skills. Online learning options in particular offer people with full-time jobs the flexibility to study at their own pace.

A particularly interesting example of part-time, distance learning is the "Viticulture Enology Science and Technology Alliance" program set up by the National Science Foundation in the United States (VESTA). While online learning is limited in the skills it can transfer to students at home, it does allow students with minimal exposure to the field of study to initiate their education. Online certificates may lead them toward higher-level institutional training programs or to simply apply for work in the wine industry where they may receive on-the-job training. In-class extension courses, often offered in evenings or on weekends to accommodate full-time work schedules, offer wine industry professionals continuing education opportunities to ensure that they keep up-to-date on industry trends and are able to fill in knowledge or skills gaps. Extension courses offered on college or university campuses may also be seen as a recruitment tool that can transition part-time students into full-time programs, or simply offer those without the time or resources to study full-time the opportunity to access high quality education in a way that accommodates their needs.

Online learning and extension learning formats may recruit new entrants to the wine industry, including people from professional spheres that are becoming more relevant to grape growing such as engineering, robotics and computer science. They may also serve to help with the retention of workers already in the industry. Once you have trained workers, it is important to ensure that they remain professionally motivated and satisfied for the long term. Informal, on-the-job training may go a long way to ensuring that workers continually upgrade their knowledge, skills and abilities to perform the work they do at the highest level, but there is almost certainly a place for more formalized and specialized training through institutions that have the research and pedagogical resources to be able to anticipate the evolution of the industry and therefore match training and education with workplace needs. Workers who feel relevant are more likely to stay motivated in their day to day activities and remain in the industry, so these programs, in combination with employer investment in their workers, is key to retention (Flowers & Hughes, 1973). At the same time, formal or informal mechanisms to transfer knowledge to workers who do not have the ability to enroll in full-time programs are necessary to ensure that workers are up-to-date; therefore Part-time courses, Extension and online offerings are needed as well.

Finding ways to access both domestic and foreign workers to ensure a sustained workforce and enable employers to meet their labour needs is an important challenge for the Ontario wine industry, and viticulture schools can play an important role in this. They can help increase awareness of careers in viticulture and try to ensure retention of workers in the industry by offering professional development opportunities in an ongoing way. Education and training options can be enhanced through flexible part-time and online training modules. Academic institutions need to work closely with industry stakeholders to ensure that the curriculum offered aligns with workplace needs, but also help the industry anticipate the future needs of the industry as the operating environment evolves in the global marketplace. Institutions such as Brock University and Niagara College must attract talented entrants to the industry in the first place, but also foster skills that allow graduates to adapt and learn on the job with the changing needs of the industry.

3.0 CONCLUSIONS

My travels to diverse winegrowing regions to speak with researchers and teachers at oenology and viticulture institutions helped me to hone in on several topics which are especially relevant to the global grape and wine industry in 2019. These are topics that are key components of research and training curricula in any wine region - including Ontario. Themes that repeatedly arose included climate and environmental issues (especially with reference to climate change), the need for pathogen free and robust planting stock, efficient and sustainable farming and processing methods, the use of technology, mechanization, precision viticulture techniques and automation, and cultivating and sustaining a viable workforce in the viticulture sector. These topics are substantial, complex and loaded with significance not only for grape growing but for agriculture as a whole. The grape and wine industry in Ontario must contend with each of these issues in ways that are most appropriate to the particularities of the region.

An assessment of the present state of the industry that considers both its strengths and weaknesses was conducted to determine where specific gaps and challenges exist. I have attempted to identify the best viticultural and pedagogical practices of the present day as demonstrated by a wide variety of well-respected institutions. The subject matter and strategies identified as having great potential for addressing challenges to Ontario viticulture can be researched, studied, taught and implemented in academic and applied training institutions, specializing in agriculture or viticulture. This knowledge can also be transferred to industry stakeholders, most notably to primary grape growers, through part-time courses, workshops and online offerings.

My conversations and observations with representatives from the many wine regions and educational institutions that I visited revealed that successful grape growers and wine producers must always make decisions based on a strong foundation of peer-reviewed research. This research must pertain to the specifics of grape production in a locally defined region, as conditions change substantially from place to place. Primary research is undertaken by governmental agencies or institutions such as universities, which may be public or private or both, often with the support of private funding from industry groups or associations, or in some cases, individual companies. Large wine regions in California, Bordeaux or South Africa's Western Cape have inherently more resources for this type of research than the comparably small Ontario industry. Collaborations between agencies, institutions and industry stakeholders, with both national and international partners, may serve to deepen the resource pool in the province. It is especially useful to seek partnerships with institutional bodies from somewhat similar climates and growing conditions. New York, Washington, New Zealand and parts of Northern Europe would seem to correspond well with Ontario.

It is important to recognize that not all knowledge pertaining to a local industry can be obtained through local research initiatives, therefore knowledge acquisition will also rely on outside academic sources. It is desirable to foster experts trained at a high academic level with specializations in viticulture, or other applicable fields, to interpret and apply such external work to their local industry. A few such individuals are active at a handful of post-secondary institutions in Ontario, most notably at Brock University and the University of Guelph. A few others work for federal and provincial agencies such as Agriculture and Agri-Food Canada and the Ontario Ministry of Agriculture, Food and Rural Affairs, or for not-for-profit research institutes such as Vineland Research and Innovation Center which is located in the Niagara Region. It is my opinion that more resources need to be directed towards growing this specialized workforce to help guide the industry through the rapid environmental changes that are anticipated in the 21st C.

Knowledge that is gained through domestic research projects and integrated from external sources must be transferred from the lab to the classroom and on to frontline workers to be employed in everyday grape growing activities. Both theoretical and applied education and training programs must exist and be accessible to a diverse group of current and potential vineyard workers. This ensures that workers have the most current understanding of relevant viticulture techniques and technology in support of the growth and development of the industry. Brock University and Niagara College offer formal viticulture education in Ontario, with graduates of these programs occupying most of the skilled positions in the provincial grape and wine industry. As such, it is critical that both programs incorporate the most current and relevant topics extant in viticulture in their classrooms. In my opinion, the most comprehensive and successful programs that I observed in my travels managed to integrate both high level scientific theory with practical application, or experiential learning. A structural weakness, I believe, of the currently available formal training options in Ontario is that these programs are not operated through agricultural studies departments and therefore tend to be stronger in oenology than in viticulture. Partnerships with existing agricultural colleges in the province such as the University of Guelph, with its diverse offering or Trent University and its Sustainable Agriculture and Food Systems Program might be a way to integrate methodologies which would improve curriculum.

Any Ontario viticulture program should have a sharp focus in the classroom on the mechanisms of climate science and the potential implications of a high-carbon future in Ontario's growing regions, as well as examining potential adaptations to anticipated changes in climate. They should continue to address the extreme cold winter weather and frequently wet and humid conditions in the growing season that have always posed significant challenges to growers. Sustainable production methods should also play a central part of any curriculum to ensure currency with evolving environmental policies and regulations including greenhouse gas

emissions, and responsible business practices. Vineyard owners and workers must appreciate that they are operating in complex and connected agricultural, ecological and social environments when growing grapes in wine country.

Grape breeding, nursery propagation practices and pathogen transmission and identification methods should also be core to any program since the entire industry relies on the health and consistent availability of clean and robust planting stock. They also need to ensure that students are exposed to the availability, utility and operation of the most current and sophisticated technologies available. Pertinent examples include powerful mechanical equipment for ground and canopy management and spray application, technologies associated with precision viticulture, data gathering and interpretation, automation and robotics. It is clear to me that these technologies are capable of addressing many of the challenges facing the Ontario wine industry today, assuming operators are available with the specialized skills to use them. They allow growers to react to volatile weather and uneven growth patterns in vineyard blocks by identifying and mapping sub-plots which may be defined according to any number of set performance parameters. This allows growers to level out vine performance and yields across large blocks and maximizes efficiencies in terms of human labour, energy inputs and materials usage at the same time. Automation and robotics will further reduce human labour hours in vineyards, which is critical given current shortages of available workers.

It is my opinion that relative to other winegrowing regions with larger areas suitable for planting grapes, longer growing seasons and more heat units during the growing season, Ontario is not naturally suited to growing high yields for the commodity wine market – we simply cannot compete. As such, a focus on growing premium grapes, opting for quality over quantity, to produce grapes and wines with a higher retail price point and profit margin is a better option for Ontario growers. Additionally, experimentation with cultivars and wine styles to produce unique or specialized wine products would allow Ontario's producers to capture important market niches. Viticulture schools in the province can help support these efforts by specifically addressing best practices for premium growing and designing technical lessons in specialized winemaking styles involving unique grape varieties or processing methods for the benefit of the industry.

Based on my travels, it is evident that post-secondary education and training institutions have a central role to play in recruiting talented people to work in viticulture and winemaking in their respective regions. They can also help ensure good retention rates in the industry by providing modes of education that allow for full-time workers to update their knowledge and skills, as exemplified by various extension and online learning formats at many of the institutions that I visited.

My belief that education and training programs in Ontario are key to addressing critical challenges that the grape and wine industry are facing now, or will likely face in the future, has been further solidified by the survey work that this Nuffield Scholarship has allowed me to carry out. Our industry and our viticulture schools have already demonstrated a large capacity to adapt and respond to external challenges and pressures imposed by the natural world or by economic circumstances. It is incumbent on these stakeholders to search for solutions in an ongoing way and to keep pace with the rest of the world in this global industry. My conclusions from this study lead to several recommendations which may be helpful in this regard.

4.0 RECOMMENDATIONS

- Institutions must match traditional viticulture training methods with awareness and proficiency of the most current mechanical and digital technology tools available to the global industry. These institutions must deliver these core lessons in both theoretical/academic and applied/experiential methods of instruction.
- Institutions must ensure that students understand and can apply core principles and methods of sustainable grape and wine production in a multi-faceted way.
- Institutions must play a key role in the recruitment and retention of vineyard workers and offer training in multiple formats including full-time degrees and diplomas, part-time course offerings, professional development workshops, seminars and online training.
- Institutions must form domestic and international partnerships with other research facilities, universities or applied training colleges, to maximize their access to funding, facilities and human resources and thus be able to serve a diverse population of students. Articulation agreements, student exchange programs, international internships and online course offerings are some of the ways to enlarge the capacity of small viticulture schools.
- Institutions must work closely with domestic industry stakeholders, particularly those who represent commercial grape growers and processors, to establish learning outcomes for their programs, but must also refer regularly to international standards to keep pace with the most current knowledge and innovations available.
- More resources need to be directed towards encouraging the growth of a specialized workforce of researchers and academics to help guide the industry through the rapid environmental changes that are anticipated in the 21st C.
- The industry and tertiary education institutions that support it should focus on the premiumization and specialization of wine styles within the global wine market as we are not environmentally suited to compete successfully in the bulk commodity market.
- All grape and wine industry stakeholders, including tertiary training institutions, must heavily support the nascent Canadian Grapevine Certification Network and endeavor to promote its mandate in a thorough and coherent manner to safeguard the future of the industry.

5.0 GLOSSARY AND ABBREVIATIONS

BAG - Consortium of Bordeaux, Adelaide and Geisenheim Universities involved in specific research project work using pooled resources.

Biodynamic - A method of farming., and sometimes wine production, that is related to organics in its abstinence from synthetic pesticides and fertilizers, and which views the farm holistically as a closed but diverse ecological system and takes into account non-conventional factors such as lunar and planetary cycles to guide management decisions

CAGR – Compound Annual Growth Rate. The rate of return for an investment to grow from its beginning balance to its ending balance assuming profits are reinvested at the end of each year.

Cultivar - A selected and cultivated variety of a plant, including grape vines of the Vitis vinifera wine grape species

CGRCP - California Grapevine Registration & Certification Program

CDFA - California State Department of Food and Agriculture

CVA – Canadian Vintners Association

ELISA - enzyme-linked immunosorbent assay. An immunological assay used to measure antibodies, antigens, proteins etc. in biological samples

FAO – Food and Agriculture Organization of the United Nations

GDD - Growing Degree Days. Units measuring heat accumulation used to help anticipate crop and pest development.

GDP - Gross Domestic Product

GLRaVs - Grapevine Leafroll-associated Viruses

GIS - A geographic information system. A systematic framework for gathering, managing, mapping/visualizing and analyzing geographical data

GGO – Grape Growers of Ontario. Organization representing Ontario's grape farmers.

GPS - Global Positioning System. A global navigation satellite system that uses satellites, a receiver and algorithms to provide location, velocity and time data for air, sea and land travel.

"GRAPE" project - GroundRobot for vineyArd monitoring and ProtEction. A project involving the design and manufacture of a land-based autonomous vehicles with a robotic arm

GRBV - Grapevine Red Blotch Virus

ha - Hectare

ICB – International Canadian Blend

INRA - National Institute of Agricultural Research (France)

IPCC – Intergovernmental Panel on Climate Change (United Nations)

IRSTEA - National Research Institute of Sciences and Technology for Environment and Agriculture (France)

LiDAR - Light Detection and Ranging. A surveying method that measures distance to a target by illuminating a target with laser light and measures reflected light with a sensor.

Mt – million metric tons

M = million

NDVI - Normalized Difference Vegetation Index. A graphical indicator that quantifies vegetation by measuring the difference between near-infrared and red light based on reflective and absorptive capacities.

Organic farming - An alternative farming system that allows the use of "naturally" occurring substances while prohibiting or strictly limiting synthetic substances.

PCR - Polymerase Chain Reaction. A method used in molecular biology to rapidly make millions to copy and amplify DNA and amplify it in order to study it in detail.

Première Cru - literally, "First Growths." a sub plot of growing land within the Burgundy wine region in France denoted as consistently producing high quality wines.

SAWP - Seasonal Agricultural Workers Program (Canada)

Ton - metric ton = 1000KG

UAV - Unmanned Aerial Vehicle. Colloquially also known as "drones."

USA – United States of America

USDA - United States Department of Agriculture

UV-VIS-NIR spectrum - Describes spectral ranges covering the wavelengths 190–400, 400–765 and 765–3200 nanometers, respectively.

Vegetative propagation - Asexual propagation techniques used to produce new plants (vines in this case) from existing plant tissue

VESTA - Viticulture Enology Science and Technology Alliance (USA)

VQA – Vintners Quality Alliance. A regulatory and appellation system which guarantees quality and authenticity for Canadian wines made in Ontario or British Columbia.

6.0 REFERENCES

Agriculture and Agri-Food Canada. (2016). Crop profile for grape in Canada, 2016 (80 pages) – synopsis. Retrieved from the Government of Canada website: http://www.agr.gc.ca/eng/science-and-innovation/agriculture-and-agri-food-research-centres-and-collections/ontario/pest-management-centre/pesticide-risk-reduction-at-the-pest-management-centre/crop-profiles/crop-profile-for-grape-in-canada-2016-80-pages-synopsis/?id=1535557895449

Agriculture and Agri-Food Canada. (2017). An overview of the Canadian agriculture and agri-food system 2017. Retrieved from the Government of Canada website: http://www.agr.gc.ca/eng/about-us/publications/economic-publications/an-overview-of-the-canadian-agriculture-and-agri-food-system-2017/?id=1510326669269

Alba-Lois, L. and Segal-Kischinevzky, C. (2010). Beer & Wine Makers. *Nature Education, 3*(9):17. Retrieved from https://www.nature.com/scitable/topicpage/yeast-fermentation-and-the-making-of-beer-14372813

Antes, A. (2018, August 2). Personal Interview.

Arthur, R. (2019, February 8). 'The organic wine world is in full expansion mode - and shows no signs of stopping!'. Retrieved from https://www.beveragedaily.com/Article/2019/02/08/Organic-wine-market-continues-to-grow#

Armbruster Kelterei-Technologie. (n.d.). GrapeSort Optical Sorter. Retrieved from http://www.rotovib.de/en/grapesort-optical-sorter

Aurand, J.-M. (2014). State of vitiviniculture world market. *International Organization of Vine and Wine* [PowerPoint slides]. Retrieved from www.oiv.int › medias › state-of-the-world-vitiviniculture-oiv-2018-ppt

Australian Wine Research Institute, The. (2015). Wine history wiki. Retrieved from https://winehistory.com.au/

Block, K. (2018, January 31). Personal Interview.

Blouin, M. (2019). *We're #1 in the nation and #2 in the world for agriculture and forestry.*

Retrieved from UC Davis website: https://caes.ucdavis.edu/news/1-in-nation-agriculture-and-forestry

Briotet, Christophe. (2018, July 2). Personal Interview.

Canadian Agriculture Human Resource Council. (2016). *Vacant jobs in agriculture costs producers $1.5B and impacts Canadians.* Retrieved from http://www.cahrc-ccrha.ca/news-events/news/vacant-jobs-agriculture-costs-producers-15-b-and-impacts-canadians

Canadian Horticultural Council. (2016). *Fruit production in Canada.* Retrieved from https://www.hortcouncil.ca/en/about-us/horticulture-stats/about-ushorticulture-statsfruit-production-in-canada/

Canadian Vintners Association. (2018, May 15). *Economic Impact.* Retrieved from http://www.canadianvintners.com/economic-impact/

Carpin, S., Goldberg, K., and Vougioukas, S. (n.d.). RAPID - robot assisted precision irrigation delivery. (n.d.). Retrieved from http://rapid.berkeley.edu/

Chambers, P. J., and Pretorius, I. S. (2010). Fermenting knowledge: the history of winemaking, science and yeast research. *EMBO reports, 11*(12), 914–920. Retrieved from https://www.researchgate.net/publication/47756004_Chambers_PJ_Pretorius_IS_Fermenting_knowledge_the_history_of_winemaking_science_and_yeast_research_EMBO_Rep_11_914-920

Chew, G. (2017). Vineyard land values in Niagara. Retrieved August 19, 2019 from http://blog.gregchew.com/blog/vineyard-land-values-in-niagara

Cholette, S., Castaldi, R. and Fredrick, A. (2005). The globalization of the wine industry: Implications for old and new world producers. Retrieved from https://www.researchgate.net/publication/265748503_The_globalization_of_the_wine_industry_Implications_for_old_and_new_world_producers

Cool Climate Oenology & Viticulture Institute. (n.d.). Vine-alert. Retrieved from http://www.ccovi.ca/vine-alert/recent

Cornell College of Agriculture and Life Sciences. (n.d.). NCPN webinar series: clean plants for the

future. Retrieved from https://grapesandwine.cals.cornell.edu/extension/ncpn-webinar-series-clean-plants-future/

DroneAG. (n.d.). Drones for spraying. Retrieved from https://droneag.farm/drone-spraying/

Employment and Social Development Canada. (2019, August 22). Hire a temporary worker through the seasonal agricultural worker program: overview. Retrieved from Government of Canada website: https://www.canada.ca/en/employment-social-development/services/foreign-workers/agricultural/seasonal-agricultural.html

Erasmus+. (2019). Retrieved from https://eacea.ec.europa.eu/erasmus-plus_en

Eurecat (2015). GRAPE – Ground Robot for Vineyard Monitoring and Protection. Retrieved from https://eurecat.org/en/portfolio-items/grape/

Flowers, V.S., Hughes, C.L. (July, 1973). Why Employees Stay. Harvard Business Review.

Food and Agriculture Organization of the United Nations. (n.d.). Banana facts and figures. Retrieved from http://www.fao.org/economic/est/est-commodities/bananas/bananafacts/en/

Forsyth, P. (2017). Niagara's rate of growth soars by more than 300 per cent. *Niagara This Week.* https://www.niagarathisweek.com/news-story/7205518-niagara-s-rate-of-growth-soars-by-more-than-300-per-cent/

Gil, Emilio. (2018). Lecture on Spray application in vineyards around the world. New technologies for a sustainable crop. Presentation at Vitinord 2018 Conference, Sweden.

Grape Growers of Ontario (2010). History. Retrieved from https://www.grapegrowersofontario.com/history

Grape Growers of Ontario. (2018). Grape facts. Retrieved from https://www.grapegrowersofontario.com/grape_facts

Grape Growers of Ontario. (2018). Grape prices. Retrieved from https://www.grapegrowersofontario.com/grape-prices

Hochschule Geisenheim University. (n.d.). Geisenheim FACE Experiments: An Outlook on Our

Atmospheric Future. Retrieved from https://www.hs-geisenheim.de/en/research/research-profile-projects/face/

Jones, G. V. (2011). Sustainable vineyard developments worldwide. *Internet Journal of Enology and Viticulture*, *7*(3). Retrieved from https://www.infowine.com/intranet/libretti/libretto9016-01-1.pdf

Jones, G. V. (2018, June 19). Personal Interview.

Ker, K.W. (2010). A case study investigation of the learning needs of the Niagara grape and wine community (Doctoral dissertation). Brock University, St. Catharine's, Canada.

Lallemand, P. (2018, June 25). Personal Interview.

Lambri, M. (2018, July 11). Personal Interview.

McGovern, P., Jalabadze, M., Batiuk, S., Callahan, M.P., Smith, K.E., Hall, G.R., Kvavadze, E., Maghradze, D., Rusishvili, N., Bouby, L., Failla, O., Cola, G., Mariani, L., Boaretto, E., Bacilieri, R., This, P., Wales, N., and Lordkipanidze, D. (2017). Early Neolithic wine of Georgia in the South Caucasus. *Proceedings of the National Academy of Sciences of the United States of America, 114*(48), E10309–E10318. Retrieved from https://www.pnas.org/content/114/48/E10309

Moss, Russell. (2018, December 13). Personal Interview.

Myles, S., Boyko, A.R., Owens, C.L., Brown, P.J., Grassi, F., Aradhya, M.K., Prins, B., Reynolds, A., Chia, J.-M., Ware, D., Bustamante, C.D., and Buckler, E. S. (2011). Genetic structure and domestication history of the grape. *Proceedings of the National Academy of Sciences, 108*(9), 3530–3535. Retrieved from https://www.pnas.org/content/108/9/3530

Mussell, A., Stiefelmeyer, K., Oginskyy, A., Schmidt, C., and Seguin, B (2010, December). Aligning the Ontario Grape Supply and Demand: A Varietal Plan for the Grape and Wine Industry Final Report. George Morris Centre.

Naio Technologies. (n.d.). Vineyard weeding robot TED. Retrieved from https://www.naio-technologies.com/en/agricultural-equipment/vineyard-weeding-robot/

National Soil Database. (2014). Plant hardiness zones in Canada. Retrieved from the

Government of Canada website: http://sis.agr.gc.ca/cansis/nsdb/climate/hardiness/index.html.

Natural Resources Canada. (2019). Canada's changing climate report. Retrieved from the Government of Canada website: https://www.nrcan.gc.ca/maps-tools-and-publications/publications/climate-change-publications/canada-changing-climate-reports/canadas-changing-climate-report/21177.

Niagara Region. (n.d.). Niagara agriculture profile and economic impact analysis. Retrieved from https://www.niagararegion.ca/living/ap/raeis_download.aspx

Nicolas, K. (2018). Lecture on the past, present, and future of climate change and wine: Global and local opportunities and challenges. Presentation at Vitinord 2018 Conference, Sweden.

OIV. (2018). State of vitiviniculture. (2018). Retrieved from http://www.oiv.int/en/technical-standards-and-documents/statistical-analysis/state-of-vitiviniculture

Ontario Craft Wineries. (2017). Sustainable winemaking Ontario moves to an accredited certifiable program. Retrieved from https://ontariocraftwineries.ca/sustainable-winemaking-ontario-moves-to-an-accredited-certifiable-program/

Ontario Federation of Agriculture and Environmental Defence. (2015). *Farmland at risk: why land-use planning needs improvements for a healthy agricultural future in the Greater Golden Horseshoe.* Retrieved from https://d3n8a8pro7vhmx.cloudfront.net/greenbelt/pages/2544/attachments/original/1449244985/2015-11-18-Farmland_at_Risk-highres_WEB_(1).pdf?1449244985

Ontario Ministry of Agriculture, Food and Rural Affairs. (2019). Impacts of cold temperatures on wine grapes. Retrieved from http://www.omafra.gov.on.ca/english/crops/hort/news/hortmatt/2014/01hrt14a1.htm

Ontario Ministry of Agriculture, Food and Rural Affairs. (2019). Wind machines for minimizing cold injury to horticultural crops. Retrieved from http://www.omafra.gov.on.ca/english/engineer/facts/10-045.htm

Parker, B. (2016). Inspiring Gen Z to consider careers in agriculture and food. Retrieved from

Nuffield Canada website: https://static.wixstatic.com/ugd/fadf46_01e9887c0a5d4921871a778634f0f366.pdf

Ponti, L., Gutierrez, A., Boggia, A., and Neteler, M. (2018). Analysis of grape production in the face of climate change. *Climate, 6*(20). Retrieved from https://www.researchgate.net/publication/323936922_Analysis_of_Grape_Production_in_the_Face_of_Climate_Change

Rhoads, D. (2017). History of cell biology. *BiteSize Bio.* Retrieved from https://bitesizebio.com/166/history-of-cell-biology/

Riesen, R. (2018, July 4). Personal Interview.

Robinson, J., Harding, J., and Vouillamoz, J. (2012). Wine grapes: a complete guide to 1,368 vine varieties, including their origins, flavours and wines. London: Penguin.

Rosenfeld, H.J. (2018, July 31). Lecture on Development of early ripening varieties. Presentation at Vitinord 2018 Conference, Sweden.

Schmid, J. (2018, July 27). Personal Interview.

Schmitt, M. (2018, July 27). Personal Interview.

Shaw, T. (n.d.). The implications of climate change for the Ontario wine industry. *Brock University Department of Geography and Cool Climate Oenology and Viticulture Institute.* [PowerPoint slides]. Retrieved from http://www.climateontario.ca/doc/publications/TonyShawOCCIAR_SC.pdf

Shumate, J. (January 29, 2018). Personal Interview.

Statistics Canada. (2019). Control and sale of alcoholic beverages, year ending March 31, 2018. Retrieved from https://www150.statcan.gc.ca/n1/daily-quotidien/190423/dq190423a-eng.htm

Stocker, T.F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V., and Midgley, P.M. (2013). IPCC, 2013: summary for policymakers. *Climate Change 2013: The Physical Science Basis.* Retrieved from https://fdocuments.in/document/summary-for-policymakers-pdf.html

Striegler, K. (2018, January 29). Personal Interview.

Terral, J.-F., Tabard, E., Bouby, L., Ivorra, S., Pastor, T., Figueiral, I., Picq, S., Chevance, J.-B., Jung, C., Fabre, L., Tardy, C., Compan, M., Bacilieri, R., Lacombe, T., and This, P. (2010). Evolution and history of grapevine (*Vitis vinifera*) under domestication: new morphometric perspectives to understand seed domestication syndrome and reveal origins of ancient European cultivars. *Annals of Botany, 105*(3), 443-455. https://doi.org/10.1093/aob/mcp298

Vanden Heuvel, J. (2018, December 13). Personal Interview.

van Leeuwen, C., and Darriet, P. (2016). The Impact of Climate Change on Viticulture and Wine Quality. *Journal of Wine Economics, 11*(1), 150-167. Retrieved from https://www.cambridge.org/core/journals/journal-of-wine-economics/article/impact-of-climate-change-on-viticulture-and-wine-quality/2914947821F9A182508E76760E7C0D9B

Van Zyl, S. (2018). Personal Interview.

Varelas, V. (2018). Lecture on Sustainable oenology and viticulture: new strategies and trends in wine production. Presentation at Vitinord 2018 Conference, Denmark.

VINBOT. (n.d.). Powerful precision agriculture tool. Retrieved from http://vinbot.eu/

Vineyards Media LLC. (2020). Wine Map of Canada. Retrieved from https://vineyards.com/wine-map/canada

Vision Robotics Corporation. (2017). Intelligent autonomous grapevine pruner. Retrieved from https://www.visionrobotics.com/vr-grapevine-pruner

VQA Ontario and Deloitte. (2019). Ontario wine and grape industry performance study 2018. Retrieved from http://www.vqaontario.ca/Library/Documents/OntarioWineandGrapeIndustryPerformanceStudy_2018Report_Final_Optimized.pdf

Vintners Quality Alliance of Ontario. (2019). VQA Ontario appellations of origin. Retrieved

from http://www.vqaontario.ca/Appellations

Washington State University. (2016). Virus diseases. Retrieved from http://wine.wsu.edu/extension/grapes-vineyards/grape-diseases/virus-diseases/

Willwerth, J. (2014). Research report: use of geotextiles to reduce freeze injury in Ontario vineyards. *Cool Climate Oenology & Viticulture Institute.* Retrieved from http://www.grapegrowersofontario.com/sites/default/files/Report%20geotextile%20willwerth%20Feb%202013.pdf

Willwerth, J., Ker, K., and Inglis, D. (2014). Best management practices for reducing winter injury in grapevines. *Cool Climate Oenology & Viticulture Institute.* Retrieved from https://brocku.ca/ccovi/wp-content/uploads/sites/125/Research-Best-Practices-Manual-Winter-Injury.pdf

Wine & Spirits Education Trust (2012). Wine and spirits: understanding wine quality (2nd ed.). London: Wine & Spirits Education Trust.

Yamaha Motor Corporation. (2016). Precision agriculture. Retrieved from https://www.yamahamotorsports.com/motorsports/pages/precision-agriculture

Zimmerman, L.B. (2019). Invasion of the vineyard robots. *Wine-Searcher.* Retrieved from https://www.wine-searcher.com/m/2019/03/invasion-of-the-vineyard-robots

Zion Market Research. (2018). Wine market by colour (red wine, rose wine, white wine and others), by product type and by distribution channel: global industry perspective, comprehensive analysis and forecast, 2017 - 2023. Retrieved from https://www.zionmarketresearch.com/report/wine-market

Zoecklein, B. (2018). How climate change affects winegrowing. *Wines Vines Analytics.* Retrieved from https://winesvinesanalytics.com/features/article/195134/How-Climate-Change-Affects-Winegrowing

7.0 APPENDICES

7.1 The History and Evolution of *Vitis Vinifera*

The selection and domestication of the wild grapevine *Vitis Sylvanus* seems to have occurred sometime between the seventh and fourth millennia BC in the Transcaucasian region between the Black and Caspian Seas (Terral et al, 2010). Because this species is vegetatively propagated with ease, domesticated cultivars spread relatively quickly through the Near East, Middle East and eventually to Central Europe through the transport of cuttings. In each of these places, further selections and eventual crossings occurred, resulting in an estimated 5,000-10,000 individual cultivars on six out of seven continents in the present day (Wine and Spirits Education Trust, 2012). There is great genetic diversity built into the species as it is very prone to mutation, a trait that has allowed wine grapes to fill a wide swath of environmental niches within generally temperate latitudes and which may provide resilience to the species and to the people who cultivate it in the face of rapid environmental changes associated with shifts in climate and weather patterns across the globe.

Evidence of ancient winemaking dating to the period of 6000-5500 BC has been discovered at sites in present day Georgia and Armenia (McGovern et al., 2017). Occurrences of wine production are determined through the verification of concentrated amounts of tartaric acid - incontrovertible evidence of vinification - found in clay pottery. While some of these residues may have derived from the foraging of wild grapes and not from systematic viticultural endeavors, the domestication of the grapevine has been clearly identified to have occurred in the same period through measurable mutations in grape seed morphology in archaeological samples (Myles et al, 2011). The fact that grape juice will ferment spontaneously due to the presence of naturally occurring yeasts in the ambient environment and on the grape skins themselves meant that “winemaking” would simply transpire with the gathering, crushing and storage of grapes in a liquid tight vessel. No significant knowledge base or technology was required for humans to arrive at a liquid that was both resistant to spoilage and instilled a sense of euphoria in the drinker: wine was destined for success (Chambers & Pretorius, 2010).

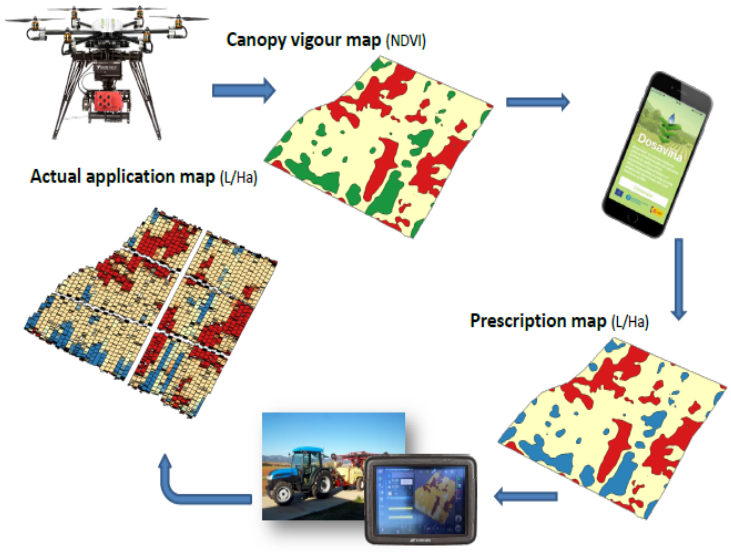
From the Near East and Eastern Mediterranean regions, grape cultivation spread westwards into Crete and mainland Greece by the fifth millennium BC, then to Italy by the ninth century BC. With the conquest and spread of the Roman Empire, viticulture was well-established in most of Europe as well as India and China by 500 BC. Wine grapes travelled with European colonial powers from the 16th century onwards and wine industries appeared in Mexico, South America and California alongside Spanish conquistadors and missionaries. Portuguese explorers and missionaries brought *Vitis vinifera* cuttings East to Japan in the 16th century, and vines were planted in Australia and New Zealand in the early 1800s, all laying the groundwork for the “New

World" of wine regions, many of which would come to compete for global market share with traditional winegrowing regions in the "Old World" of Europe (Australian Wine Research Institute, 2015).

7.2 Plant Hardiness Zones

Plant Hardiness Zones refer to the physical areas in which plants are considered likely to survive seasonally (National Soil Database, 2014). The zones take several variables into account, such as minimum temperatures or duration of frost-free seasons (National Soil Database, 2014). Within Canada, the zones range from 0 - 8, where 0 is harshest. Canada's Plant Hardiness Zones map can be found at http://sis.agr.gc.ca/cansis/nsdb/climate/hardiness/index.html (National Soil Database, 2014).

7.3 Dosaviña



(Gil, 2018)

8.0 LINKS

Avize Viti, Champagne Region, France: http://www.avizeviticampus.fr/

Cal Poly Wine and Viticulture Program, San Luis Obispo, California: https://wvit.calpoly.edu/

Canadian Grapevine Certification Network: https://www.cgcn-rccv.ca/site/about-cgcn

Cool Climate Oenology and Viticulture Institute, Brock University, St. Catharines, Ontario, Canada: https://brocku.ca/ccovi/

Changins: https://www.changins.ch/home.html

Cornell University, Ithaka New York, U.S.A: https://grapesandwine.cals.cornell.edu/

Efficient Vineyard Project: https://efficientvineyard.com/project-participants

Edmund Mach Foundation, Trentino Alto-Adige, Italy: https://www.fmach.it/eng/About-us

Escuolo Enologico, Conegliano, Italy: https://www.cerletti.gov.it/pvw/app/TVII0001/pvw_sito.php

Eventad Center for Wine Education, Linfield College, Oregon, U.S.A: https://www.linfield.edu/wine.html

Geisenheim Face2Face website: http://www.face2face.center/

Geisenheim University, Geisenheim, Germany: https://www.hs-geisenheim.de/en/studies/prospective-students/degree-programs/viticulture-and-enology-bsc/

Grape Growers of Ontario: https://www.grapegrowersofontario.com/

Elsenberg Agricultural Training Institute, Western Cape South Africa: http://www.elsenburg.com/services-and-programmes/elsenburg-agricultural-training-institute#s=Diploma-in-Agriculture--Cellar-Technology

Fresno State University Department of Viticulture and Enology, Fresno, California: https://www.fresnostate.edu/jcast/ve/

The Intergovernmental Panel on Climate Change: https://www.ipcc.ch/

International Organization of Vine and Wine: http://www.oiv.int/

Lycee Viticole de Beaune: https://lycee.lavitibeaune.com/lycee/index.php/fr/

Montpellier SupAgro Euromast VInifera Program: https://en.montpellier-supagro.fr/training/vinifera-euromaster

New York Vineyard Site Evaluation System: http://arcserver2.iagt.org/vll/Default.aspx

Nova Scotia Community College, Cool Climate WIne and Viticulture Studies Program, Canada: https://www.nscc.ca/learning_programs/programs/PlanDescr.aspx?prg=WINE&pln=VITICULTUR

Okanagon College Viticulture and Wine Studies, British Columbia, Canada: https://www.okanagan.bc.ca/Programs/Areas_of_Study/fwt/Viticulture_and_Wine_Studies.html

Terroir Congress, Zaragoza, Spain: http://www.terroircongress.org/en/

Unified Grape and Wine Symposium, Sacramento, California: https://www.unifiedsymposium.org/

Università Cattolica del Sacro Cuore, Piacenza, Italy: https://www.mastersportal.com/studies/135965/viticulture-and-enology.html

University of Guelph, Ontario Agricultural College: https://www.uoguelph.ca/oac/

University of California, Davis: https://wineserver.ucdavis.edu/#/

Vintners Quality Alliance of Ontario: http://www.vqaontario.ca/Home

VitiNord Conference: http://www.vitinord2018.org/