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The Feasibility, Practicality and Uses of Detecting Crop Water Stress in Southern Ontario Apple Orchards with a UAS

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Thomas Tiidus

Abstract

UAS (Unmanned Aerial Systems) are becoming more common place in agricultural sites around the world. While the accuracy of achieving NDVI (Normalized Difference Vegetation Index) from a UAS is well understood, few studies have attempted to acquire other plant health attributes such as CWSI (Crop Water Stress Index), particularly in horticulture such as apple orchards. In addition, no academic studies up to the time of this writing have explored the perceived usefulness of data obtained from a UAS for the average farmer. This study explored the practicality and feasibility of using UAS for apple orchards in Southern Ontario. This study sought to find out if NDVI and CWSI can be accurately obtained from a UAS for apple orchards and if this data can be feasibly obtained and is practical for the average Ontario apple farmer. By flying a UAS over a volunteer orchard and conducting charrette style interviews with orchard owners with the obtained data, the results showed that data is indeed useful to the farmers, despite improvements needed for CWSI accuracy. However, this data is only useful during key times of the growing season and obtaining this data, while feasible, requires planning and logistics around weather and government red tape. This study has laid the ground work for future studies to use as a staging point to improve CWSI estimate accuracy, create new methods of observing health attributes or diseases in apple orchards, and obtain more information on the usefulness of UAS data for Ontario farmers.

1.0 Introduction

Remote sensing is a long-establishing and expanding method of data collection and analysis that has proven to be highly beneficial for precision agriculture (Dawson 1998). Through remote sensing, spatial information can help predict future crop yields, monitor water and nutrient stress in crops, and detect disease outbreaks. Rapid technological developments in remote sensing and spatial analysis software allow farmers the potential to collect tremendous amounts of conceivably beneficial data. The recent availability of relatively low-cost, unmanned aerial systems (UAS, or ‘drones’) has spurred growing interest in the use of UAS-mounted camera-based sensors to observe crops and collect field-level data from directly overhead, especially for spatially extensive grain and other cash crop fields (Torres-Sánchez 2014). However, the suitability of the many potential remote sensing tools and methodological techniques varies considerably from one crop, field, and agricultural system to another, and many have yet to be thoroughly tested in the field (Taghvaeian et al 2013). For example, there is a particular lack of research on how best to apply technologies like hyper-spectral, multi-spectral and thermal camera sensors (UAS-mounted or otherwise) to production of crops other than cereals. One example of this are apple orchards. In addition, there is little research on the farmer’s perspective of the technology, what it can offer, if it’s practical in the use of their business, and if the data obtained is useful. This study is field assessment of the viability and issues of using drones and remote sensing technology for data collection and the feedback from farmers that may help optimize crop yields using apple orchards as a case study.

Apples are currently one of the most economically important non-cereal crops in Ontario, with a total crop area of 16,000 acres in Ontario, and value close to $60 million (OAG, 2015).

Apples are considered a high yield crop, as the acreage to pounds of fruit harvest ratio is high compared to many other crops. As such, growers consistently look for ways to ensure their crops are well watered and healthy. A major factor that affects the health of a crop a crops is water stress. Water stress occurs when a plant has little access to water in the soil around it. This typically occurs during periods of drought, although early stages can occur when the plant simply does not have enough water during growth. This can have major impacts on the plants growth and development that can lead to lower crop yields or even crop failure, and thereby having adverse effects on a famer's harvest income. Plants absorb water through their roots, and when soil moisture is low, plants will expend more energy to try and absorb more water. This extra effort and energy will also reduce the plants photosynthesis efficiency as the stomates in the plant close to conserve water. Consequently this will result in the plant expending more energy to absorb water and simultaneously taking in less energy. Long periods of water stress will cause plants to wilt and even die (Bauder 2003). Currently most farmers rely on traditional observation methods in determining their crops' water stress as well as other nutrient needs, diseases and general crop health. These traditional methods usually consist of the farmer walking his/her own field and observing the field with their own eyes with the knowledge gained from either personal or generational experience or education. Because this method relies on the grower to walk their own field, this can become very time consuming and can result in the farmer missing certain sections of the field, particularly if they own very large fields and orchards. Apple growers would benefit from having more real-time information about moisture availability in their orchards, identification of trees that are under stress, or any general information on their crop health. Having this information given in a more contextual/concise format or in a more efficient format can help growers make better educated decisions on how to maximise the productivity of their field and to identify problem areas early. Such results which can be obtained via a camera sensor mounted on a UAS.

Early recognition of crop water stress is crucial to prevent these negative impacts and maintain a healthy crop (Bauder 2003). Researchers have developed the Crop Water Stress Index (CWSI) (Idso et al, 1981) as a means to quantifiably monitor how well watered crops are. CWSI quantify how well watered a plant is. This information can be used by farmers and growers to determine which portions of their field need to be watered or irrigated, and by how much. Thus in theory, a grower having this data in a timely manner contextualized in a map of their field could find trouble spots of their field to irrigate or spray. This could save them water costs for irrigation as it is traditionally applied to the entire field as it will centre primarily on needed areas. This data contextualized in a map can also save the farmer the time spent in inspecting their fields via traditional methods or in confirming issues also identified via traditional methods. It could also possibly identify previously unnoticed problem areas. This same data can also assist the grower in developing strategies to remedy any issues that are identified. A crucial component of calculating the CWSI of a crop is to acquire the crop or canopy temperature. This is typically acquired with thermal sensors detecting wavelengths in the infrared spectrum (IR 1.3-5.0 µm). Crop canopy temperature is often cooler then air temperature as the plant’s transpiration cools it. Another factor that may be important to growers and possibly related to CWSI values are digital elevation model (DEM) values. A DEM shows the elevation and slope of a surface area, and can display the elevation of a study area and provide each point with a value. In a hilly environment, areas of a low DEM would be at a lower elevation, which means that more water would likely collect in these areas. As a result, crops located in a low DEM could be collecting more water which could have a positive impact on their CWSI value. Knowing the DEM data of their fields, farmers could take steps to maximise the water distribution efficiency of their field. In addition, a DEM of the field can help the grower further visualise their general knowledge of their field and be used in a variety of future personal projects for the grower. This research project used UAS-mounted cameras to determine if these datasets can be successfully captured from orchards using UAS-mounted cameras.

To further explore the impacts these correlations may have on the crops, these values will be correlated with Normalized Difference Vegetation Index (NDVI) values. NDVI is a ratio of near infrared (NIR 0.7 to 1.1 µm) to Red (R, 0.4 to 0.7 µm) wavelengths measuring the plants overall "greenness" or photosynthetic activity and is often used as an indicator of the overall crop health and assists in predicting the crop yield. My research also aimed to identify if CWSI, NDVI and DEM indices are obtainable by using a UAS equipped RGB (Red Green Blue), NIR (Near Infrared) and IR (Infrared or thermal) camera sensors. This research further looked at if such information were obtainable, would the information of these indices and methods used to acquire them be useful or practical to the average Ontario apple grower?

In exploring these questions, this study included a systematic literature review of the use of camera sensors for pre-harvest applications in apple orchards and previous applications of UAS's for measuring CWSI. Taking the knowledge learnt from this literature review, the study then developed and tested a methodology to obtain CWSI, NDVI and DEM values in apple orchards using a UAS. After the flights, semi-structured interviews with the growers were conducted. Results of the UAS flights were presenting and discussing and the suitability and practicality of the information and methods in regards to the farmer’s own growing operation/industry were explored. While various technical and logistical issues were encountered during the data collection, the resulting interviews showed that UAS's do have a large potential within the industry. The discussion further makes recommendations on how to overcome various technical and logistical barriers which were encountered during the study and how successfully to bring this technology to Ontario farmers.

2.0 Research Objectives.

This research sought to answer the following questions: Can UAS-mounted cameras be used to detect water stress in an apple orchard? Is there a spatial correlation between CWSI values, DEM values and NDVI values in an apple orchard when obtained on a RGB, NDVI and thermal camera based sensors mounted on a UAS? Do these values line up with the ones acquired through ground truthing? If there is a correlation, how strong is it? Does the correlation or any of the individual data provide useful information for the average Ontario apple grower? What other data obtained from a UAS would be useful to farmers? Are the methods used simple and affordable for the average Ontario apple grower? If not, how would farmers prefer to obtain this data and at what cost?

This research is timely as there is currently very little research on the use of camera based sensors for apple orchards (Wang 2012) and none for sensors on UAS's in apple orchards, despite the economic importance of apple crop for Ontario growers. Having a greater understanding of how UAS's can monitor farms to detect water stress and general plant health could allow growers to make changes to irrigate their fields more precisely and efficiently, thereby save on water costs and usage and possibly increasing crop yield. This aspect may become even more important, as climate change is expected to bring greater periods of drought to Southern Ontario (Penney 2012). Findings from this research could provide growers with a new form of adaptation. One that is relatively inexpensive and easy to implement. The following is an overview of the topics covered in this project and the methods I used to conduct my research.

3.0 Background

3.1 Overview of the Apple Industry in Ontario

In recent years, the Ontario apple crop has averaged about 0.25 million metric tonnes or 13.7 million bushels, with investments can exceeding $25,000/ha (Gardner, 2016). As of 2013, there were approximately 215 major apple growers in Ontario. Close to 20 different varieties of apples are grown on 16,000 acres in Ontario, and value close to $60 million, which includes sales to fresh and processing markets and on-farm/pick-your-own (Gardner, 2016).. The major apple growing areas of Ontario are located along the shores of Lakes Ontario, Erie, Huron, Georgian Bay, as well as along the Niagara Escarpment.

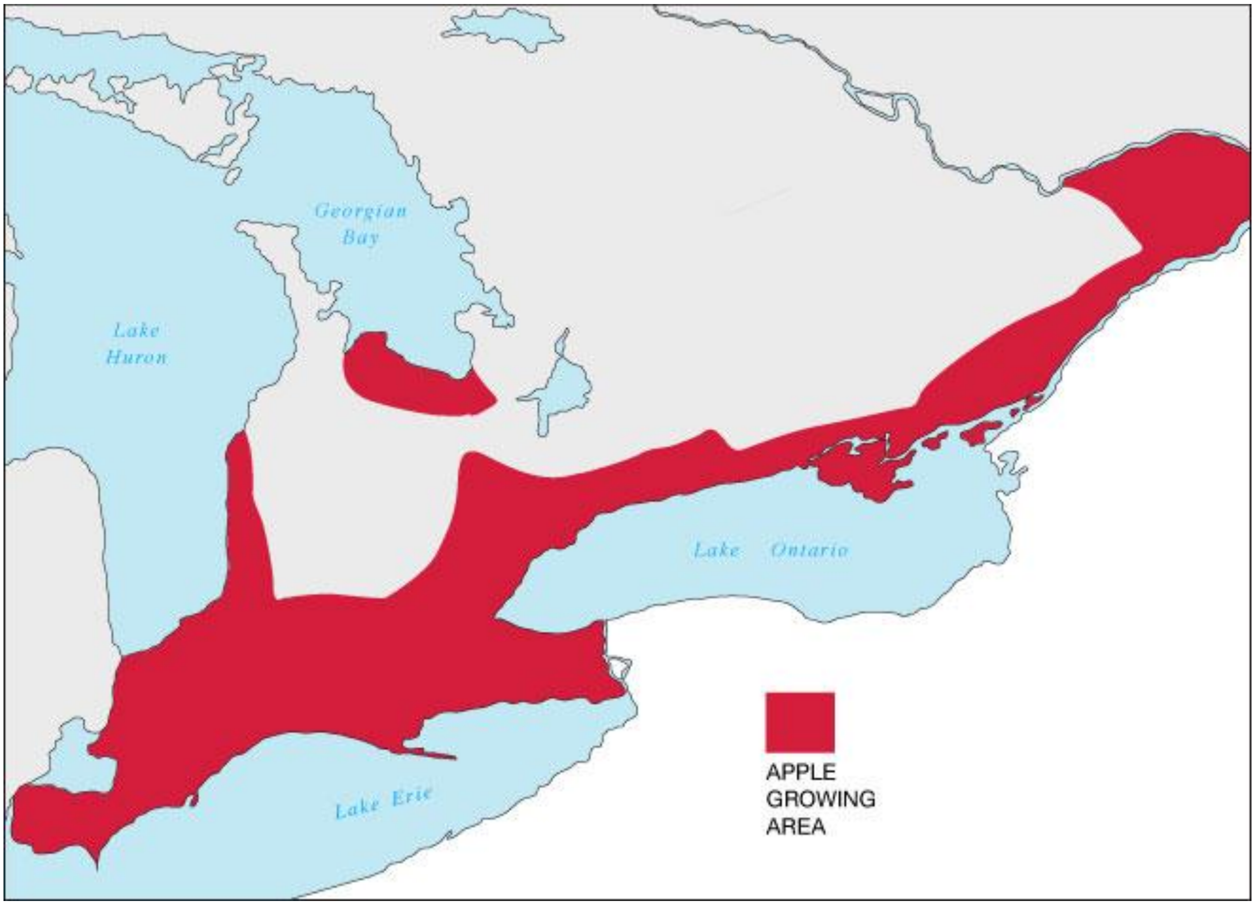


Figure 1: Apple growing regions of Ontario (OAG, 2015), with the majority along the shores of Lake Ontario and Lake Erie

The lakes along with the escarpment moderate temperatures and with fertile sandy loam soils allow a productive area for horticulture. The industry is both labour and capital intensive with investments of up to $10,000/acre in establishing an orchard (Gardner, 2006). As with most forms of agriculture, a return on investment is unpredictable, with production costs ranging from $3,500-$4,000/acre. There are however various safety net programs such as crop insurance available for the industry (Gardner, 2006). There is currently a trend within the industry in converting older orchards with standard trees which require ladders for harvesting, to dwarf trees which in the field resemble a more traditional vineyard style field and employ pedestrian harvesting. Dwarf trees are shown to be more efficient as they require much less space and thus can yield higher crop in a smaller area without too much concern for requiring extra irrigation.

50% apples harvested are marketed as fresh apples. 75% of this portion is sent to packers and distributed through grocery stores, while the last 25% are sold on site, roadside stands and farmers markets. The other 50% of the apples harvested are used in processing. 90% of this portion is used for making juices and cider (non-alcoholic and alcoholic), while the remaining 10% is used in a variety of products including applesauce and pies. 10% of all apples harvested are exported (Gardner, 2006). The Ontario Apple Growers (OAG) acts as the marketing board for the crop and regularly negotiates prices for apple products and provides industry leadership, research and public relations among other services (Gardner, 2006). Currently, water supply for apple growers is not a chief concern due to the crop being drought resistant and the general availability of water in Ontario. However, recent studies in climate change have shown that increasing temperatures in Southern Ontario, and may increase risk and crop vulnerable to drought. In the Niagara region by 2050, there could be an average increase of 3-4˚C with a 20% decrease in overall rainfall, with rain events occurring less frequently, but with greater precipitating more during these rainfall events (Jenny 2012). These conditions will lead to more heat waves and drought like conditions. New drought extremes are likely to occur, and surplus water often proves critical in the cases of extreme drought (Juhász 2008). Although apple trees are hardy and can be sustained for periods of drought, these new extremes may prove to be too much for some orchards to handle. In addition, the drought resilience only applies to fully grown apple trees, as saplings are particularly vulnerable to the effects of drought. Apple growers, who have a better understanding of where water is needed in their field, can optimize their water-use efficiency in times of water stress. An increase in water-use efficiency is crucial to agricultural production, rural development, and environment protection (Várallyay 2007).

3.2 Use of UASs and Camera Sensors in Agriculture

Research into the use of UAS's in the agriculture industry is growing. Herwitz et al (2004) was among the first researchers to look into the feasibility of low flying UAS's in agriculture decision making. Herwitz et al (2004) demonstrated the UAS could be not only be manoeuvred safely over a coffee plantation in Hawaii, but also that the images obtained from the true colour and multi-spectral cameras were useful in identifying invasive weed outbreaks and for revealing irrigation and fertilization anomalies. Most commonly, UAS have been used with camera sensors to identify NDVI values after studies such as Hunt et al (2005) have shown the potential with using NDVI sensors on UAS's.

NDVI is a method which measures the overall "greeness" of a plant. Live green plants absorb solar radiation in in the process of photosynthesis. The pigment in plant leaves, chlorophyll, strongly absorbs visible light (from 0.4 to 0.7 µm) for use in photosynthesis. The cell structure of the leaves, on the other hand, strongly reflects near-infrared light (from 0.7 to 1.1 µm). By calculating the difference in the near-infrared light and the blue wavelengths of light, the NDVI of a plant is given. Generally, the greener the plant is, the healthier it is overall, thus healthier or "greener" plants have a higher rating NDVI. Since this discovery further studies such as Zhang & Walters et al (2014) and Jensen et al (2014) have been conducted using NDVI as a measure to identify positive correlations for various agricultural practises. Because of the relative ease and simplicity of obtaining accurate NDVI values from a UAS, a new service industry has sprung up with companies offering UAS services to farmer clientele. These services include providing UAS flights and image/data interpretation, and certain UAS models (such as the one used in this study) have NDVI features or sensors built in to it. However, while the use of NDVI and UAS's are well understood, the majority of this research and business applications are targeted at cash crops such as wheat, corn and soybean, with less focus on horticulture. In addition, while NDVI is well understood, further research is still being conducted to understand other potential applications of camera sensors on UASs, such as disease identification, nutrient stress and water stress.

3.2.1 UAS's and Crop Water Stress Observation in Agriculture

Using camera based sensors to monitor crop water stress is an area that has been well researched. While some research has used multispectral or hyperspectral sensors in detection of crop water stress, thermal sensors are widely regarded as providing the best accuracy and are used as a comparative standard when developing crop water stress detection in other sensors (Zarco-Tejada 2013). This is largely due to the fact that in the IR spectrum, water exhibits a strong absorption from the vibrations of the water molecules.

Taghvaeian et al (2013) explored the possibilities and limitations of thermal sensing for monitoring crop water stress from observations taken on the ground. The methodology developed was used for observing crop water stress for all types of crops, using a handheld thermal camera with the temperature pixel values converted to a variable in the CWSI using the Arc GIS program. The method was adjusted depending on the type of plant. For example, corn (maize) plants shade themselves such that there can be shade/sun temperature differentials of up to 5°C within a study plot, while in a grape vineyard temperature variation due to self-shading ranges only up to 3°C.

Across a variety of crops, Taghvaeian et al (2013) demonstrated that thermal sensors enable real-time imaging and can provide values per pixel that are more precise than older methods such as thermometry, which can only provide an averaged value. The authors viewed favourably the ease of use, accessibility, and relatively low cost of handheld camera sensors, but found that an important limitation was that thermal camera sensors were typically not designed with agriculture in mind. Most currently available commercial thermal camera sensors have been developed for building or machine inspection, with features specific to these applications. Another important barrier to the use of these techniques for agriculture purposes is that, in most cases there is no accompanying software for image processing, meaning potential users cannot begin analyzing data quickly or simply.

Recent studies have shown that camera sensors mounted on a UAS's are capable of producing accurate CWSI values. Studies such as Taghvaeian et al (2013), Bellvert et al (2013) and Baluja et al (2012) all found that measurements from a thermal camera are best done during the noon hour when the sun is at the zenith. This is because the shading effect during this time is minimal and will prevent any data skewing due to morning dew.

To achieve their results, Bellvert et al (2013) flew a UAS with attached thermal sensors at specific heights during the solar zenith. They found that high resolution cameras would be needed, or at least a camera capable of obtaining a resolution 0.3m of vine canopy per a pixel. This is the minimum resolution needed in differentiating canopy temperatures from soil temperature, due to the narrow width of the grape vine canopy when viewed from directly overhead. The lower the camera’s resolution, the closer it would need to be flown to the canopy. The authors’ UAS-based approach would appear to be a simpler and less expensive method than using aerial images and hyperspectral sensors mounted to manned aircraft, which was the approach taken by Delenne et al (2010) to automatically detect, delineate and characterize grape vineyards from the air.

Beluga et al (2012) and Zarco-Tejada et al (2013) both experimented with using multispectral sensors to identify crop water stress indices and compared their results to measurements taken from thermal cameras. The Zarco-Tejada et al (2013) study focussed on, the use of camera sensors in evaluating and interpreting a Photochemical Reflectance Index (PRI) as an as an alternative to the more established CWSI indicator for water stress in grape vineyards. The authors suggested that this new index can detect xanthophyll pigment changes due to water stress while at the same time considering the chlorophyll content levels and canopy coverage reduction caused by stress. They did this by taking a standard PRI index and normalizing it by Renormalized Difference Vegetation Index (RDVI) and by a red edge index sensitive to chlorophyll (R700/R670). In the end, the authors found their method to be more accurate than previous PRI indices, but to be only similarly accurate to traditional CWSI methods employing thermal cameras. Baluja et al (2012) conducted a more one-to-one comparison of multispectral cameras with thermal cameras in generating a variety of indices. Their research made use of a variety of methods and equations in acquiring spectral indices, and as well employed a complex masking algorithm called *r.watershed*, originally developed by Metz et al. (2011) (enhanced by Cohen et al (2011)) to extract canopy information in palm orchards.. However, through this method Baluja et al (2012) concluded that the thermal imagery and derived indices from them can be considered as a short-term response. The indices based on the thermal images show the plant water stress at the time the picture was taken. While the spectral vegetation indices from the multispectral camera show the result of cumulative water deficits over time. Thus thermal sensors are used to determine the current water stress of the crop, while hyperspectral sensors display the water stress the plant has undergone during the growing season. Baluja et al (2012) states that while both cameras are able to present different results that demonstrate crop water stress, both methods are needed to effectively monitor overall water stress. However, if thermal sensors are able to give a snap shot as Baluja et al (2012) states, then a canopy with multiple flights and a well-documented system would be able to achieve similar results to the multispectral camera.

3.3 Systematic Review of Literature on the Application of Camera Sensors and UAS's in Apple Production

3.3.1 Methods Used for the Literature Review

In researching the literature for this project, there were no published information found that explored the use of camera mounted sensors on UAS's for apple orchards. In fact, it was difficult to find any literature on the use of camera sensors for apple pre-harvest fields. Because of this lack of content, I adopted a systematic literature review to assess the use of camera based sensors on apples. This system of review implements many of the common techniques used in health science research and that has been applied in environmental research by Ford et al (2011) and McLeman et al (2013), among others. A systematic literature review of this type involves using structured, explicitly defined key-word searches of scholarly databases and standardizes, repetitive procedures to create an inventory of potential candidate publications pertaining to predefined research questions. The inventory is scrutinized using standardized criteria to select all publications pertaining to the research questions, harvest the relevant data, and conduct a critical appraisal.

For this review, the following questions were posed:

- Are camera based sensors being used to collect observational data in apple orchards?
- If so, what types of camera sensors have been used?
- What is being observed?

- What methods are being employed?

Once the questions were established, a keyword search was performed in the journal search engine "Web of Knowledge”, specifically "Web of Science". This search engine was chosen as it is considered by many to one of the most comprehensive and widely used search engines available for English language peer reviewed journals (Jasco, 2005, Ford et al 2011, McLeman et al 2013). Boolean combinations of the English keyword terms ‘‘camera* sensor*’’ AND ‘‘apple*’’ were initially used. The search for apples retrieved 35 results. The indices of the journals most frequently represented in this selection were deliberately reviewed to verify that publications potentially suitable for inclusion were not overlooked by the search engine (no additional documents were identified in this way).

All the documents’ abstracts were reviewed based on standardized inclusion/exclusion criteria, which required that in each document:

- The focus was on the use of camera based sensors to observe an aspect the crop health or yield
- The observations were made at the farm, field, or individual plant scale; and
- The use of the sensors took place only during the pre-harvest duration of the crop, and not during or after harvest.

From the 35 documents found only one article meet the inclusion criteria. Because of this a wider search was initiated, with new keyword combinations used that focused in on particular types of sensing technologies, such as "hyperspectral AND apple*", "thermal AND sensor*AND apple*". This greatly expanded the number of articles to which could apply to the inclusion/exclusion criteria; for example, 45 additional articles were found using the key terms "multispectral AND apple*". Once the inventory of articles was created that met the inclusion criteria, then the reference list for each of these were studied to identify other potential publications for inclusion. This process was continued until a saturation point was reached (i.e. where no further potential candidate articles could be identified through key-word search or through sampling of reference lists).This left us with a final inventory of six articles focusing on the use of camera-based sensors in apple production (which included four articles for which the abstract was in English but the main text was in Chinese).

3.3.2 Results

Given the relatively small number of articles in the inventory, a statistical meta-analysis was not conducted but instead a simple categorization and qualitative analysis was created of the articles according to the utility of various types of camera sensors in monitoring water stress, nutrient stress, crop yield estimation, and disease monitoring. A statistical summary of the articles is provided in Table 1 and a complete bibliography of articles reviewed is included in the Supplemental Materials.

Table 1: Statistical summary of articles reviewed for this report

Number of studies on apple orchards				
Focus of study	Water stress	Nutrient stress	Disease	Yield prediction
	2	2	3	3

Type of sensor	Hyper-spectral	Multi-spectral	Thermal	Other (e.g. RGB)
	8	0	1	2
Type of Publication	Remote Sensing	Agriculture	Spectral /Sensors	Other
	2	4	2	2 (Viticulture & Hydrology)

This chart shows that overall there is a lack of research in the use of camera sensors for apple orchards, with very little research into the use of thermal sensors, despite its prevalence in other crops such as wheat and grapes, particularly in water stress detection. However this chart shows that camera sensors for apples have considerable potential in assisting apple producers in a variety of areas. For example, Delalieux et al (2007) found that a hyperspectral sensor can detect subtle variations in reflectance that occur in the early stages of apple scab disease, while Safren et al (2007 abs) were able to observe subtle variations between green apples and leafy backgrounds, enabling them to isolate the fruit for counting and yield estimation. However the literature published on this area is very limited, and even more so in the observation of water stress on apple orchards with only Nagay and Tamas (2013) and Kim et al (2011) having research published in this area.

3.3.3 How the Literature review Findings Inform my Research Methodology

Table 1 shows that there has been some limited research into the use of camera based sensors for observing water stress in apple orchards. Nagay and Tamas (2013) found that the most sensitive indicators of water stress include changes in photosynthetic activity, such as the mutations in the plants chlorophyll content. Using an airborne hyperspectral camera the authors calculated two indices of water stress in their study, NDVI ((NIR – R) / (NIR + R)) and the water band index (WBI) which is expressed by the following equation WBI = δ900 /δ970. The WBI is a reflectance measurement that detects changes in water canopy, and was originally developed by Champegne et al (2001) for water stress detection. Their results demonstrated that the water-stressed samples showed a greater reflectance in near-infrared spectrum and a lower reflectance in the red spectrum.

Research by Kim et al (2011) explored the reflectance difference between stressed and non-stressed apple trees with a hyperspectral camera, and could detect differences even when no symptoms were seen with the human eye. The authors used various spectral indices that were calculated and correlated to water stress levels, finding that the Red Edge NDVI ($r = 0.94$) of their indices as well as the NDVI ($r = 0.82$) were highly correlated with water stress, similar to the results found by Nagay and Tamas (2013). However, Kim et al (2011) noted that the hyperspectral camera is highly sensitive to changes in ambient illumination, and thus needs to be calibrated accordingly during image acquisition. The authors speculate that a multispectral camera may be a better practical alternative to a hyperspectral camera, due to its lower costs, and its simpler overall operation. Both Nagay and Tamas (2013) and Kim et. al (2011) used hyperspectral sensors for their research in detecting water stress indices, and none considered the use of thermal sensors despite its use for water stress detection in other crops.

Based on the previous literature, it was decided to use a thermal sensor to measure water stress in the apple orchard. Thermal sensors have already been proven to be used to measure crop water stress as a quantifiable value in other crops via the CWSI with a UAS as proven by Taghvaeian et al (2013), Bellvert et al (2013) and Baluja et al (2012). While the studies that focused on water stress in apples such as Kim et. al (2011) and Nagay and Tamas (2013) used a hyper-spectral sensor. Hyper-spectral sensors are much more expensive and often too heavy to mount on a UAS. For this reason, the present methodology did not pursue looking into the identification of diseases in apples such as apple scab, as previous studies such as Delalieux et al (2007) used hyper-spectral sensors. Instead it tried to best follow the methodology outlined by Bellvert et al (2013) who had already successfully measured CWSI in grapes and followed the CWSI calculations outlined by (Idso et al. 1981). In addition, the methods employed by Bellvert et al (2013) seemed to be the most promising for wider scale implementation as they were able to achieve an accurate CWSI of the canopy without the need of a complex masking algorithm (as used, for example, by Baluja et al (2012).

4.0 Methodology

This research explored the possibility of detecting CWSI, DEM and NDVI values from a UAS mounted camera sensor, the relationships between these indices and to gauge if such methods and indices are useful and relevant to apple growers. Such correlations could provide growers new tools in detecting fixable drainage issues on their field and how much drainage can improve a crops water stress level (CWSI) and improve overall crop health (NDVI). In addition this research explored if such data is useful for apple growers and if the methods used are simple enough to be recreated and employed by the grower. Both quantitative and qualitative research approaches were used for this study. A quantitative approach was used when determining a correlation between the DEM, NDVI and CWSI, and a qualitative approach was taken during the interview section as the interest was in obtaining the participants perspective and opinions. A qualitative method was chosen to obtain this information as it is shown to best work when obtaining individual opinions (Palys, 1992).

4.1 Selection of study site and equipment

The UAS used for this project was an eBee ag mapping UAS equipped with a standard 18.2 MP WX RGB camera for creating a DEM of the orchard, an NIR camera and a thermoMAP thermal sensor to calculate the CWSI of the trees within the orchard and a NDVI camera. Full specifications for the UAS and cameras can be found in appendix A.

While I had past experiences piloting UAS's for agricultural research with previous internships, as well as analysing the imagery obtained from the camera sensors. I took further preparatory steps in receiving additional training and practise with the eBee UAS and sensor systems with the departmental lab technician and online safety workshops. This allowed me to familiarize myself with the eBee UASs navigational systems and camera sensors to ensure timely and quality data capture and general safety prior to any research flights.

These practises were also be used to determine the optimal flight altitude when acquiring imagery. As detailed by Bellvert et al (2013) a pixel resolution of at least 0.3m is needed to differentiate between canopy temperature and soil temperature, and minimizes the chance of mixed pixels. The optimal altitude of the UAS was determined by ensuring maximum coverage of the field within a single frame while maintaining a resolution of at least 0.3m or over per a pixel. Due to the environmental conditions of Romeril farm used in this study, and the flight nature of the fixed wing aircraft, it proved difficult to maintain a flight altitude low enough to obtain a resolution of 0.3m per a pixel without endangering the aircraft or breaking UAS flight rules outlined by Transport Canada.

The majority of the field work consisted of flying a UAS equipped with RGB, NDVI and thermal sensors over the apple orchards to capture the CWSI, NDVI and DEM. Two apple orchards were selected for this study. One 16 acre farm in King City, and a 100 acre farm located in Fenwick. Both had different operational characteristics, as the King City farm operated as a "pick your own apple" farm and the Fenwick farm as a larger commercial farm. Tours were conducted on these farms prior to any research flights over the orchard, in order to become familiar with the with the study area, create a flight plan, and establish a relationship with the grower. The location of this farm relative to Southern Ontario can be seen in the figure below.

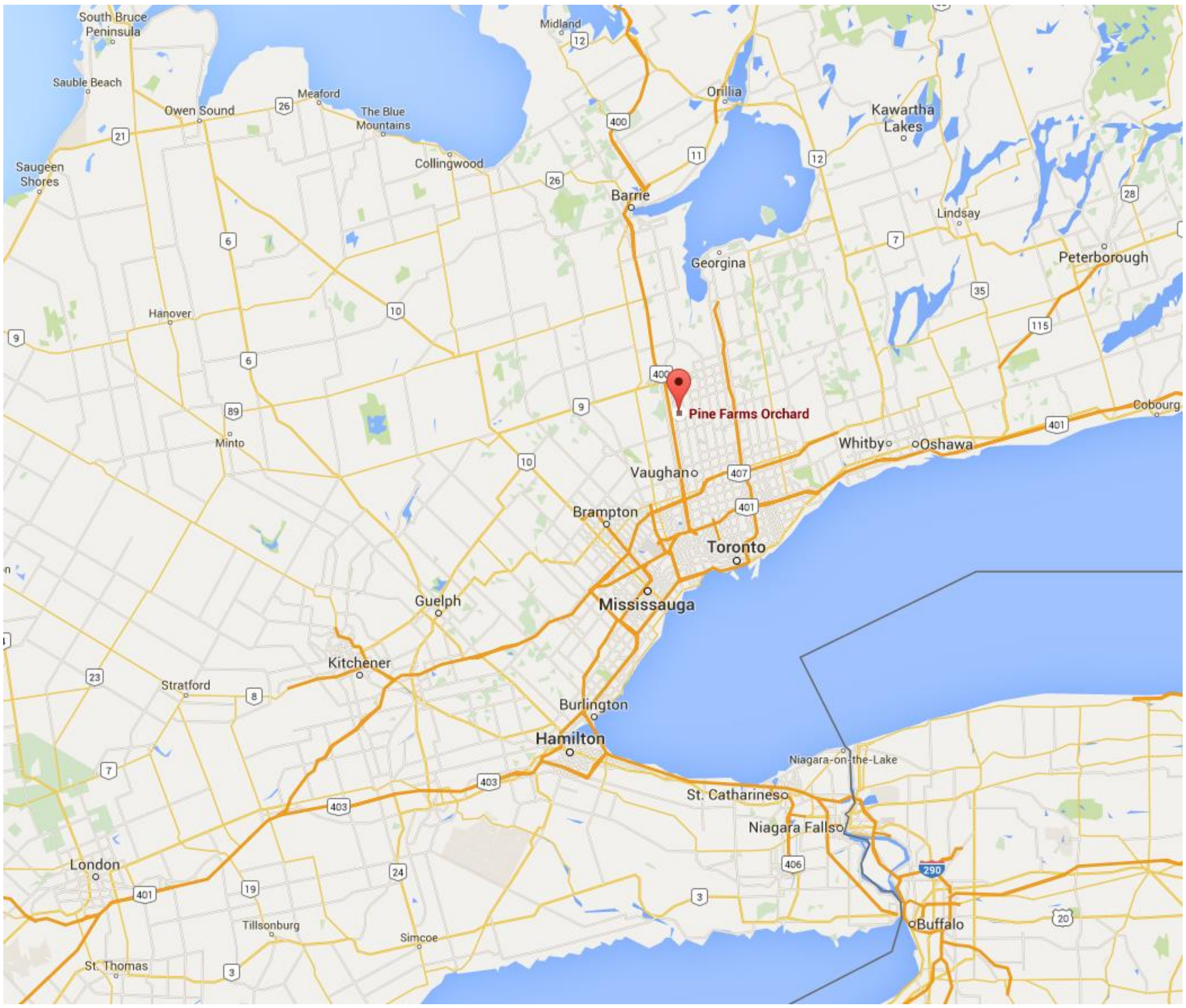


Figure 2: Location of King City Farm (Romeril Orchard) in Southern Ontario

While the Fenwick site was originally selected for this study in addition to the King City flight, it was ultimately discarded due to logistical and bureaucratic issues explained in the next section.

All flights took place on the Romeril farm near King City in summer when the apple trees leaves have fully budded and are exposed and before the apples are harvested. These were between the months June and August. The nature of this research only requires one set of flight imagery to be captured from each orchard but multiple flights were scheduled to be conducted to ensure quality raw data and to obtain a time series of the data with results of the analysis of each flight to be compared to each other to detect and observe difference and changes throughout the season. Based on the conclusions derived from Taghvaeian et al (2013), Bellvert et al (2013) and Baluja et al (2012), flights were to occur on days that are classified as sunny or partially cloudy, between the hours of 12:00 - 13:00. It is during these times that the sun is at its zenith which produces the least amount of shadow overlap ensuring the most accurate results. The flight days were decided based on local weather predictions. However, due to various logistical and technical issues experienced during the study, only one flight of each data set was conducted during this study. These issues are outlined in further detail in the discussion section of this article. In the week leading up to the first flight in mid June (NDVI and NIR), it was primarily warm and sunny with no precipitation. The average temperatures for the five days prior to the thermal flight in late August were 21°C,21°C,17°C,20°C,18°C and 14°C respectively, with less then 1mm of rain. However, the day of the flight was cloudy.

4.2 Operational steps necessary to comply with Transport Canada regulations

At the time of writing, UAS use in Canada falls into the two categories of recreational and commercial use. Transport Canada interprets the commercial use of UAS's as anything that is not recreational, i.e. flying for the fun of it. Thus, all flights conducted for the purposes of research, even if there is no commercial gain to be had, are considered commercial, with pilots needing to adhere to a separate set of rules. In most cases, pilots would need to apply for a Special Flight Operation Certificate (SFOC) from Transport Canada, which would detail the purpose of the mission, mission details, the pilot’s personal experience and competence of UAS flight, and safety and security precautions. SFOC's do not need to be filled for every commercial flight as long as they meet a criteria of exemptions outlined by Transport Canada. These criteria generally limit non-SFOC flights in rural areas with small UAS's. As such, all necessary steps were made during this study to ensure that the UAS flights would comply with the regulations outlined by Transport Canada. This included adhering to all safety requirements, SFOC exemptions or SFOC requirements outlined by Transport Canada. The eBee ag was also chosen as it was the first UAS designated as a "compliant small UAS" by Transport Canada. This expedited the process of obtaining Compliant Operator Status. An SFOC also typically features an approved term of just one year and applies to a specific region. However, holding an SFOC when an organisation has been granted Compliant Operator status brings several additional benefits including:

- Greater geographical flexibility (including Canada-wide)
- A longer SFOC validity period of up to three years
- Streamlined SFOC renewals (reducing an operator’s admin)
- And priority placement in the SFOC application queue

The eBee was chosen to help expedite SFOC applications that may have arrived for study and future studies by the University. While the all the requirements needed for a SFOC exemption were met for the King City location, however a further SFOC application was needed for the Fenwick site, due to its proximity to a local airport. A SFOC was written and sent to transport Canada approximately 6 weeks ahead of the first planned flight in June. All applications are read over by a Transport Canada employee. Normally an approval can take between 2 weeks to 2 months, depending on the volume and quality of applications at any given time. An approval from Transport Canada during this study however was not returned of until after the end of the growing season nearly 3 months later, effectively causing us to lose this study site as a result, and left us with only the King City farm site.

4.3 Remotely Sensed Data Capture

Before the UAV takes off, a flight plan was established using the eBee ag Sensefly software so that image capture encompasses the entire study area/ orchard. Because of the tall trees surrounding the orchard and the nature of fixed wing flight, the UAV had to fly higher than anticipated to avoid potentially crashing into the trees. Thus a height of 100m was chosen. During these flights, air temperature and relative humidity were also recorded, once at the beginning of the flight, again after the ~~5 minute~~5-minute mark and 10-minute mark, and once the UAV was landing. All recordings were taken at different points of the farm as well. Averages of these values were used for the CWSI equation. The UAV could only hold and operate one camera sensor at a time, so a total of three flights were conducted, one for each sensor. When flying over the field, the UAV recorded and photographed the orchard with the thermal sensor to obtain crop canopy temperature (°C) data, the RGB sensor to obtain the DEM, and the IR camera to produce a NDVI map of the field. The thermal data of the orchard gave the mean temperature readings for every pixel within the image. Prior to the flight over the orchard, the UAS spent several moments to self-calibrate its sensors to obtain accurate thermal readings. While in flight the UAS was watched to observe if there were any flight irregularities or safety issues and to adhere to Transport Canada rules. Due to logistical and technical issues, NDVI images and Thermal images where taken at different times. This resulted in slightly different geo-referencing for each image.

4.4 Data management, transformation and interpretation

The eBee is supplied with Postflight Terra 3D software, which is a programme to process, transform and manage the UAS flight imagery and data. Using this data, the pictures taken with the UAS were processed to form a georeferenced orthomosaic. This processing took several hours for each image set, and even longer with the thermal data set. During the processing, the thermal data set was prone to crashing causing us to restart to the processing for a georeferenced orthomosaic many times. It was also during this process that the Postflight Terra 3D software could automatically create a DEM from the RGB image set and a NDVI from the IR image set. This program however included the tree height when calculating the DEM. However, the tree height for the study area was fairly consistent amongst the entire field, and the data obtained proved to be relative amongst all trees. Using this software, the georeferenced orthomosaics were transformed into raster tiff files so they could be transferred and read in an ArcMap program.

While the camera was unable to maintain a resolution of at least 0.3m during flight, the thermal camera was still able to differentiate between the apple trees and other objects. The thermal camera also showed the biggest difference in spectral response levels between the apple trees and background soil and grass when compared to the spectral responses seen in any of the other cameras. Because of this, the canopy temperature values were chosen to act as a mask to extract only the apple trees within the image. This was ensuring that the remaining pixels for the CWSI equation and comparison to the DEM and NDVI would only be apple tree pixels.

This mask was achieved by using a series of tools in Arc map. Using the select by attribute tool, pixels of just apple trees with thermal images of areas >22°C. Visual inspection showed that this covered the majority of the apple trees, but also acquired other non-apple trees along the farm edge. To ensure that only the apple trees within the farm were selected in the mask, the apple tree raster was converted to a polygon which was then clipped to the study area polygon. This was then converted back to a raster and acted as a mask for the apple tree canopy values.

4.4.1 CWSI Calculation

CWSI is a common calculation used with thermal sensors when observing crops to detect and monitor water stress in plants. Originally developed by Idso et al (1981) for a variety of cash crops like corn, soybean, wheat and potato, it has expanded to a variety of different crops including grapes (Bellvert et al 2013), almonds (Roy & Ophori, 2014), watermelon (Orta et al 2003) and peaches (Paltineanu et al, 2013) The following equation was used to obtain CWSI.

$$CWSI = \frac{(dT - dT_l)}{(dT_u - dT_l)}$$

Where (dT) is the measured difference between the crop canopy temperature (°C) extracted from the thermal images, and the measured air temperature at the beginning of the flight. (dT_l) is the lower limit of the differential between canopy and air temperature, and corresponds to the value of a canopy transpiring at the potential rate, where (dT_u) corresponds to the upper limit, i.e. the value of a canopy where transpiration is completely halted. This equation will give a value between 0 and 1. A CWSI of 0 indicates no water stress, and a value of 1 represents maximum water stress. There are two different methods in acquiring the dT_l and dT_u the theoretical and empirical method. Empirical methods are considered to be more accurate, but require the creation of a Vapor Pressure Deficit (VPD) baseline chart for their crop. This requires measured differences between the crop canopy temperature and air temperature at different levels of VPD, which requires more field work to create. In addition, the dT_u of the empirical method are sometimes dependent on climate and site and can sometimes change from season to season. Once the VPD baseline chart is established, the only inputs needed are the crop's canopy temperature, air temperature and relative humidity to acquire the CWSI. This was the method used by Bellvert et al (2013), Baluja et al (2012) and Zarco-Tejada et al (2013) in the literature review portion of this document. The theoretical method is not considered to be as accurate as the empirical, but does not require the extra field work needed to create the VPD baseline chart for the study crop. However, this method requires many more calculations and measurements such as; a measurements of the study sites net radiation, albedo, wind speed, the height of the wind speed measurement, canopy height, soil heat flux, elevation, slope of the saturated vapor pressure-temperature relation, latent heat of vaporization, air density, air heat capacity, displacement height, and roughness length (wind resistance of canopy) (Jackson et. al., 1981; Jackson, 1988). Many of these calculations and measurements can be difficult to determine without the right knowledge and instruments. Due to the time constraints and scope of the study, some assumptions were made. These included the soil heat flux being approximately 10% of the net radiation in a full canopy. In addition, the theoretical CWSI was developed for the canopies of general crops and are not suited to most tree canopy conditions, such as apple orchards (Osroosh 2014).

For the purposes of this project, I employed the empirical method. This is because the purpose of this study was identified and created a potential CWSI observation method that is simple for apple growers within the industry to use. The theoretical method has many more physics based calculations that require certain degree of skill, knowledge and tools. Most of which will likely not be available to the average grower. The complexity of this method may also make it more difficult to implement into an automated system for a GIS or drone analysis program. In addition, there are 11-14 measured inputs (depending on the number of assumptions used) needed to calculate the theoretical model as compared to the 3 needed in the empirical. The high number of inputs in the theoretical model could cause confusion for the growers and increase the chances of human error of misinterpreting or mislabelling the input. Many of these inputs require other specialized instruments such as a radiometer to measure the net radiation, which itself requires training to use. The complexity of this method would likely discourage many growers as the CWSI is just one of the many factors in a crop's health, with many growers likely preferring traditional "look and feel" observation techniques due to its simplicity.

To acquire the upper and lower limits of the canopy, I employed the methods originally used by Idso et al. (1981), who accounted the changes in the upper and lower limits due to variation in vapor pressure deficit (VPD). To acquire the VPD I used the following equation:

$$VPD = \left(\frac{100 - RH}{100}\right) SVP$$

Whereas RH is relative humidity and SVP is saturated vapour pressure (Pascals). The RH was obtained through small hand held weather instruments such as a Kestral weather meter and measured pre and during the flight. SVP values are related to air temperature (°C) as seen in figure 1 and are determined from this relationship (Murray 1967).

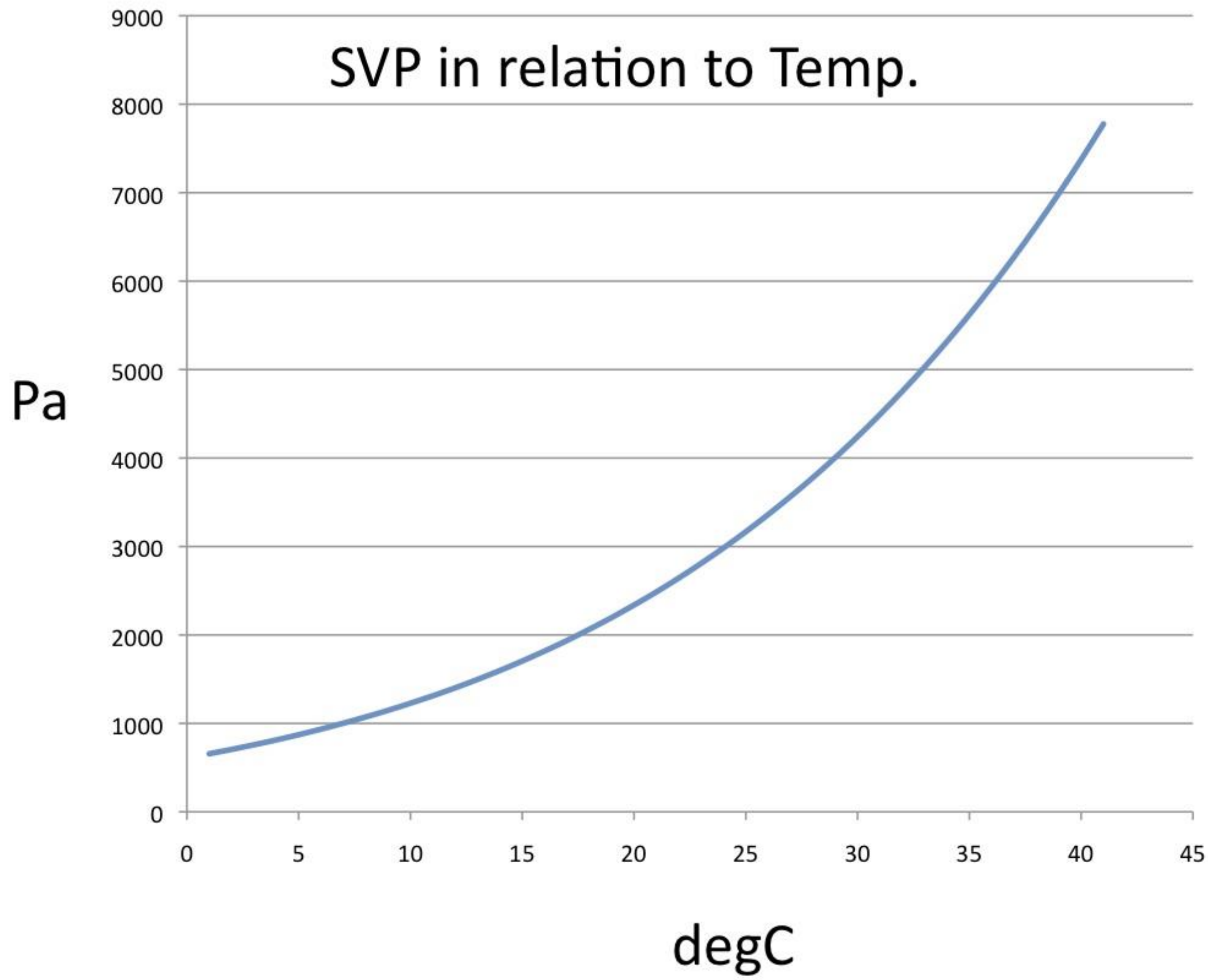


Figure 3: SVP in relation to Temperature (°C) (Murray 1967)

Idso et al (1981) states that the lower limits in the CWSI will change as a lower VPD will cause moisture to be removed from the crop at a lower rate, thus causing less cooling. Because of this, the linear function of VPD is different for a number of different crops. Figure 2 displays an example of soybeans from Idso et al (1981).

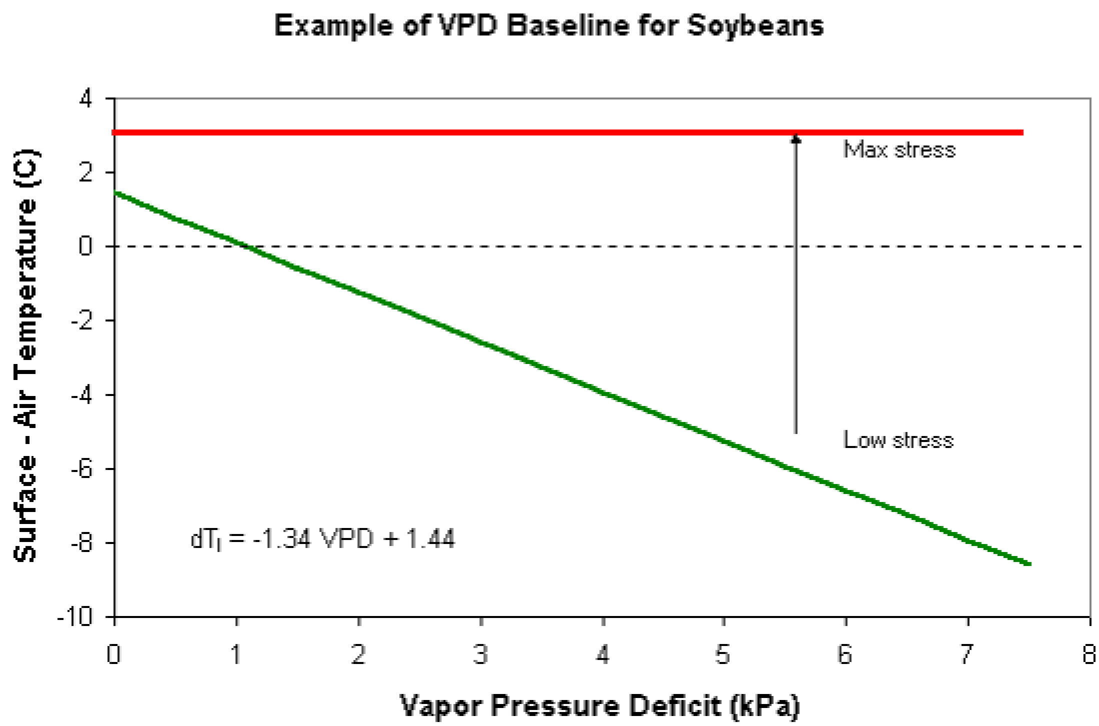


Figure 4: VPD baseline example (Idso et al, 1981)

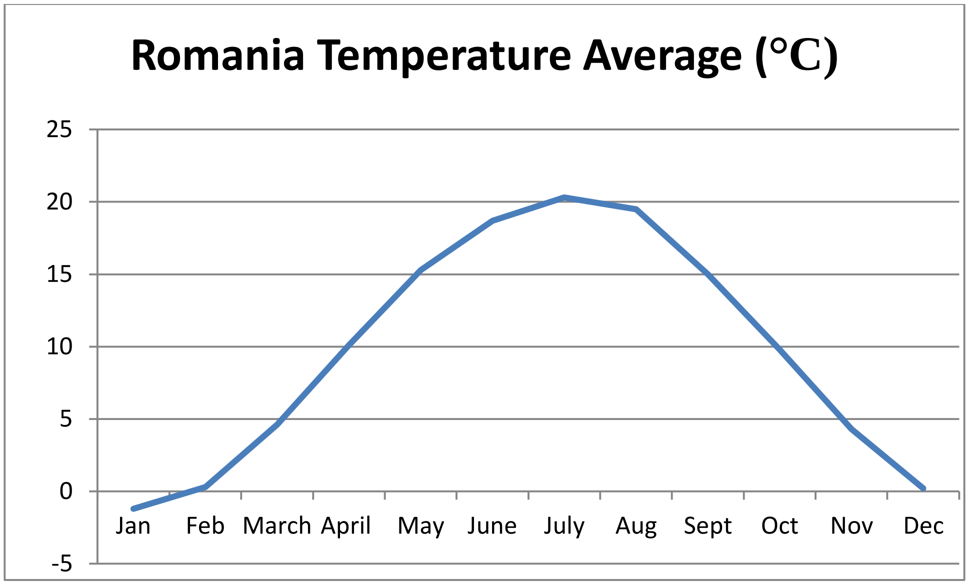
In figure 2 the green line is the non-water stressed baseline while the red line is the canopy air temperature difference for a non-transpiring plant. From this graph, the intercept and slope values are determined and used to obtain the dT_u and dT_l in following equations:

$$\mathrm{dT_l} = Intercept + Slope(VPD)$$

$$\mathrm{dT_u} = Intercept + Slope\ (\mathrm{SVP}\ \{\mathrm{t}\} - \mathrm{SVP}\ \{\mathrm{t} + \mathrm{intercept}\})$$

where VPD has units of kPa, SVP is the saturation vapor pressure at air temperature (kPa), Intercept is the intercept value for the crop of interest and slope is the slope of the crop of interest from the VPD chart. As mentioned before, VPD baselines in empirical methods can sometimes be site or climate specific for the dT_u while the dT_l is specific to the crop. Due to the scope of this study, we will be unable to create a specific VPD baseline for the study area. Thus slope and intercept values for apples in this project were inferred from the results of Chi and Growing

(2007) where the intercept is 0.1336 and the slope is -1.3152. While these results were conducted in a project in Romania, the climate of Romania is similar to that of Southern Ontario. The government of Romania's tourism website states that its nation's climate is similar to that of the North Eastern United States (Romanian Tourism 2015), which itself is comparable to southern Ontario. Figures 4 and 5 show the precipitation and temperature averages for southern Romania and King City respectively. These charts show that despite King City being much colder during the winter months, both sites have very similar temperature pattern and similar precipitation during the summer months, while Romania is much drier during the winter months.



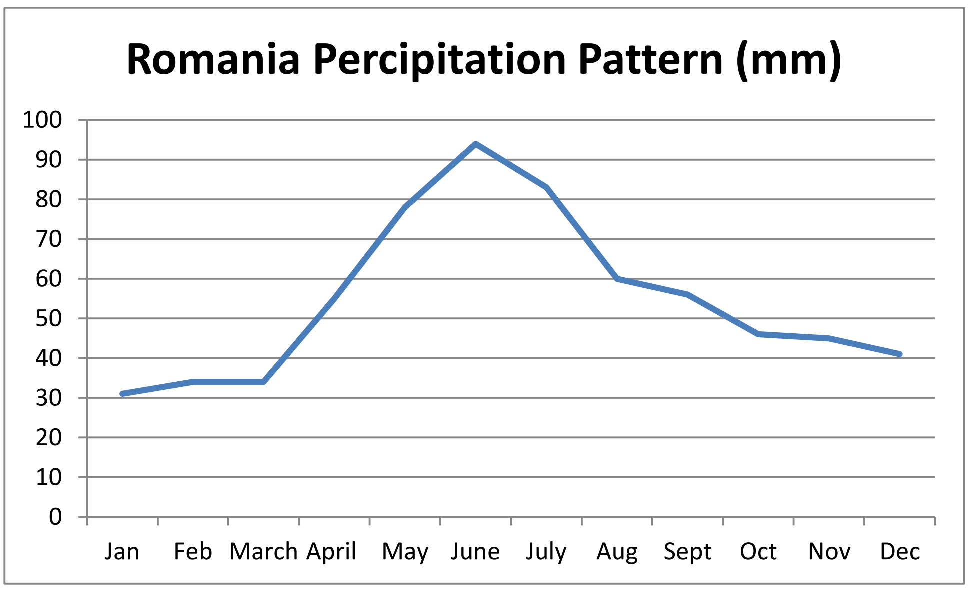
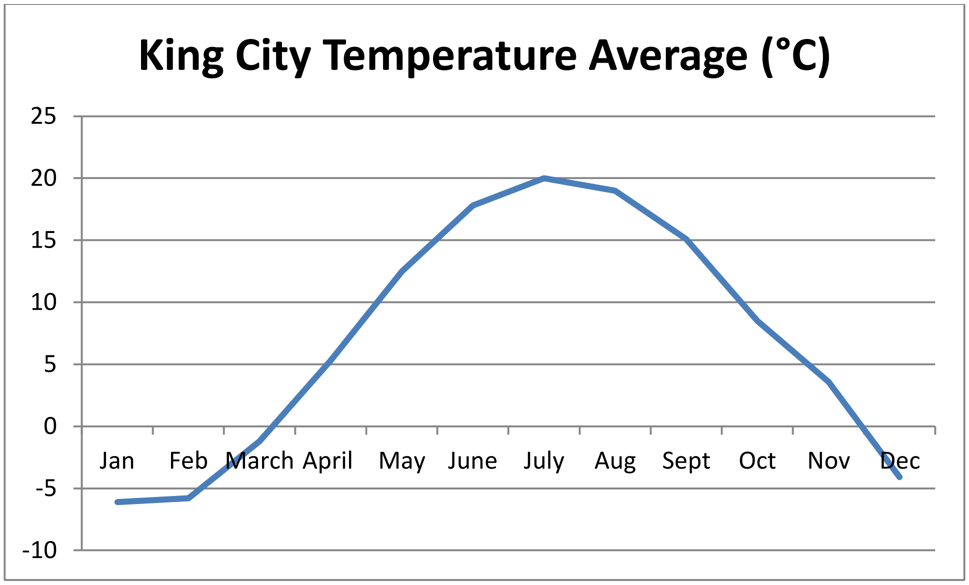


Figure 5: Temperature and Precipitation for Southern Romania, showing warm summers and cold winters retrieved from http://www.icdp.ro/en-index.php?target=en-geninf-soilclimate



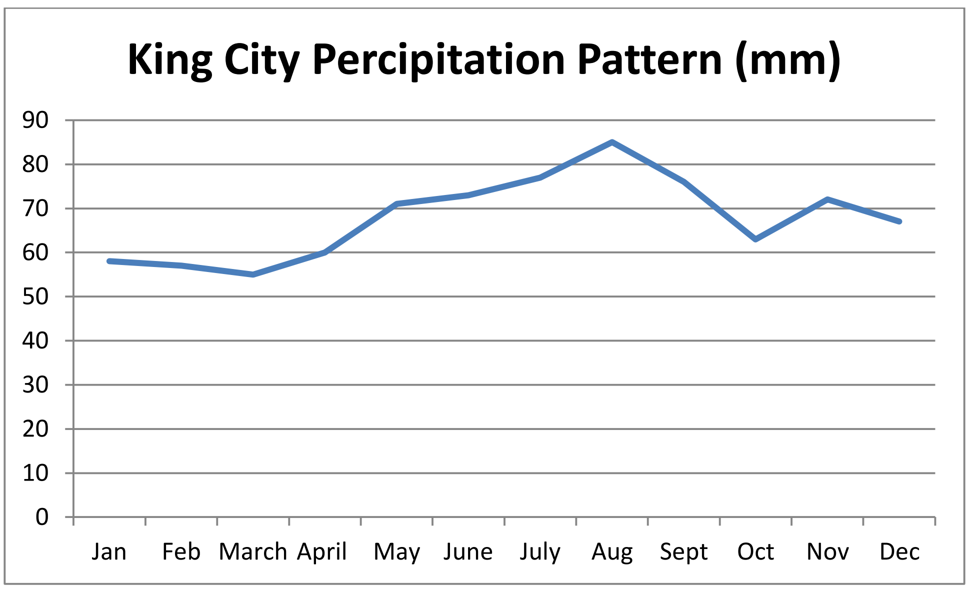


Figure 6: Temperature and Precipitation for King City, which has comparable temperatures to Romania retrieved from http://en.climate-data.org/location/768048/

This will still leave a smaller margin of error for the dT_u. There is also a difference in the soils between the two. The King City study site has a sandy loam soil, while the Romanian study site in has a clay loam. This means that the soil in study site in Romania could retain more water. This could also create a small margin of error in the end result of the CWSI for the King City site. However this was deemed this to be an acceptable range of error as when applied to an entire field, as the measurements would still be relative. A complete graph of Chi and Growing's (2007) baseline can be seen in figure 6.

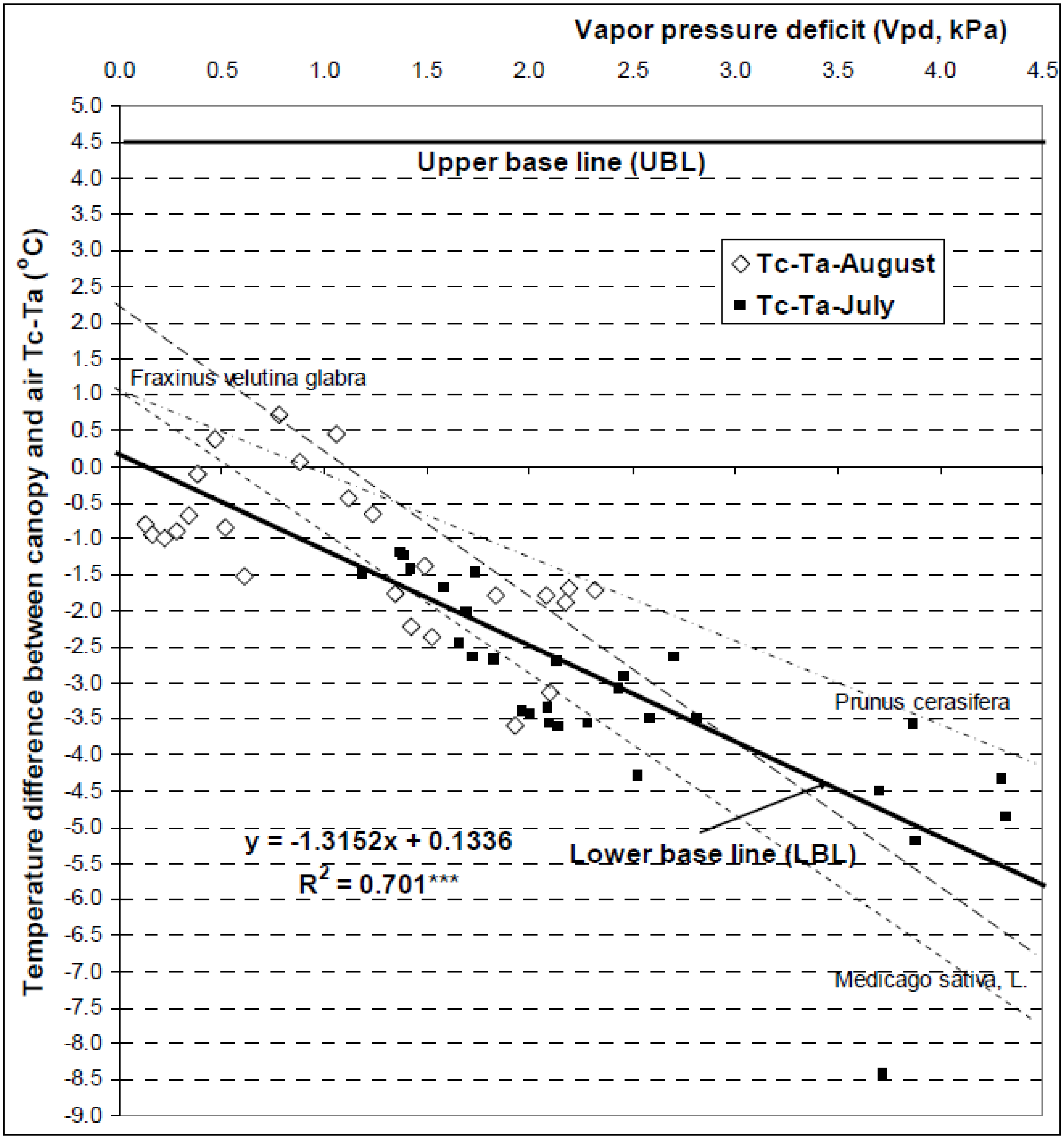


Figure 7: Chi and Growing's (2007) VPD baseline for apple

These equations were used within an ArcMap as a series raster calculator and converted into a model with the inputs of air temperature, canopy temperature and relative humidity.

A flow chart of this process can be seen in figure 7The exact steps in this model are as as follows:

1. Air Temperature Input: A Constant value of the air temperature over the study area
2. Ortho Mosaic: The ortho mosaic image of the study site. This has been masked to just cover the apple trees.
3. Output cell size: The defined output cell size of the image. This was the same as the study site.
4. Relative Humidity Input: A constant value to represent the relative humidity to be used in future raster calculations
5. Constant Air Temperature Raster Creation: The raster tool which creates a constant air temperature value
6. Constant Relative Humidity Raster Creation: The raster tool which creates a constant relative humidity value
7. Air Temperature Raster: The air temperature constant raster, resulted from the previous tool.
8. Relative Humidity Raster The relative humidity constant raster, resulted from the previous tool.
9. Raster calculation to calculate a value for the Air Temperature+ Intercept Raster Calculation: "%airtemp%" + 0.1336. This in an intermediary value which is needed to obtain the SVPt. The 0.1336 of the equation is obtained from the intercept value of the graph in Păltineanu et al (2010)
10. SVPt Raster Calculation: 610.7 * Power(10,(7.5 * "%airtemp%") / (237.3 + "%airtemp%")). This raster calculation provides the SVPt value and will be needed for the VPD.
11. Air Temperature+ Intercept Raster: the resulting raster from the calculation in part 9.
12. SVPt Raster: the resulting raster from the calculation in part 10
13. SVPt and Intercept Raster Calculation: 610.7 * Power(10,(7.5 * "% Air Temperature+ Intercept Raster%") / (237.3 + "% Air Temperature+ Intercept Raster%")) This raster creates another intermediary value as the SVPtIntercept which will be used in part 22 in the dTu calculation.
14. SVPt KPA Raster Calculation : "%SVPt%" / 1000. This simply takes the value in part 13 which was calculated in pascals and converts them to kilopascals, which is the units needed in part 22.
15. VPD Raster Calculation: ((100 - Float("%Relative Humidity%")) / 100) * "%SVPt%". Taking the relative humidity values and SVPt values we can now calculate the VPD which will serve the bases of the dTl calculation in part 23.
16. SVPt Intercept to KPA Raster Calcuation: "%SVPTIntercept%" / 1000. This simply takes the value of the SVPt raster which was calculated in pascals and converts them to kilopascals, which is the units needed in part 22.
17. SVPt Intercept Raster
18. SVPt (KPA) Raster
19. VPD Raster
20. Apple Tree Canopy Temperature Raster: this is the apple tree canopy temperatures that have gathered by the thermal camera. One of the few values in this calculation that is not a constant

and will have the largest impact on the result of the equation. This raster has also been masked to have only apple trees.

21. SVPt Intercept (KPA) Raster: another intermediary value to be used to calculate the dTl
22. dTu Raster Calculation: 0.1336 + (- 1.3152) * ("%SVPtKPA%" - "%SVPtInterceptKPA%"). This calculates the plants upper baseline biological limits. Using the slope and intercept values obtained in Păltineanu et al (2010) and used against the SVPt values obtained from the study sites air temperature and relative humidity.
23. dTl Raster Calculation: 0.1336 + (- 1.3152 * ("%VPD%" / 1000)). This calculates the plants lower baseline limits. Using the slope and intercept values obtained in Păltineanu et al (2010) and the VPD calculated earlier.
24. dT Raster Calculation: "%Apple Tree Canopy Temperature %" - "%airtemp%". Calculating the difference in temperature between the apple tree canopy obtained from the thermal camera and the air temperature.
25. dTu Raster
26. dTl Raster
27. dT Raster
28. Final CWSI Raster Calculation: ("%dT%" - "%dTl%") / ("%dTu%" - "%dTl%")
29. CWSI Raster. The final raster which provides a CWSI value in every pixel covered in the study site.

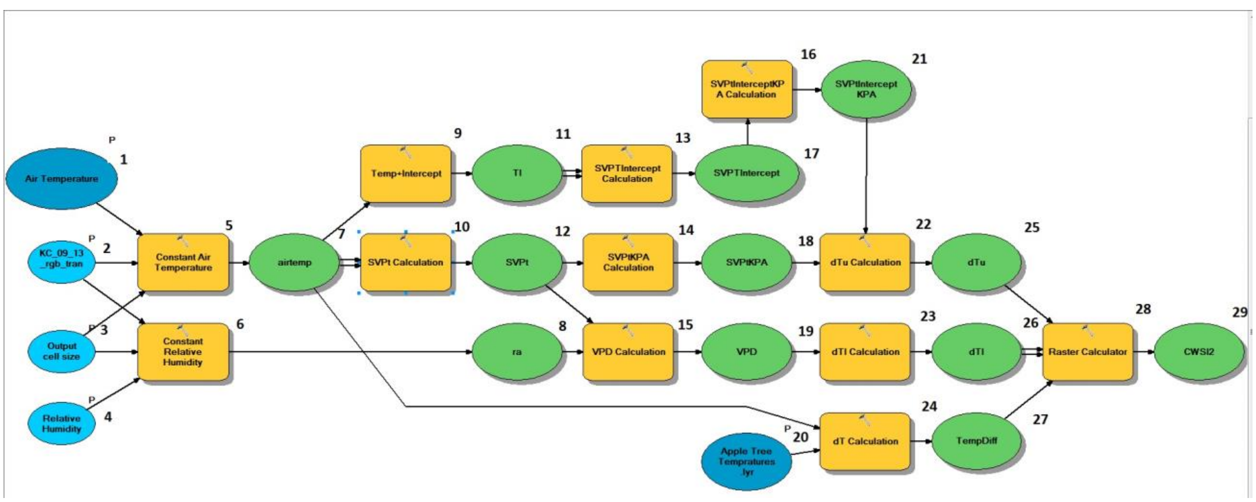


Figure 8: Steps in ArcGIS for the CWSI Model, the majority which were a series of raster calculations

This produced an image/map of CWSI of the apple orchard. This image was then overlaid with the DEM and NDVI images of the orchard for a pixel to pixel comparison of the

CWSI, NDVI and DEM values on the image. CWSI, DEM, and NDVI rasters were converted to points via raster to point commands in Arc map with point values compared to each other's respected values in a scatter plot matrix. The Pearson Product Moment R value from these graphs determined the correlation between the values. This analysis produced a series, a regular RGB image of the orchard, a thermal image of the orchard, a CWSI image for the field, a DEM image of the field, a NDVI image of the field, a scatter plot comparing the DEM and CWSI pixels of the image, an image of the displaying the DEM and CWSI correlation patterns on the orchard, a scatter plot comparing the NDVI and CWSI pixels of the image, and an image of the displaying the NDVI and CWSI correlation patterns on the orchard. These images were later used in the discussion and interview with the apple grower.

4.5 Qualitative methods to "ground truth" and interpret data

Interviews with the grower were conducted and used as a source of ground truth for the data obtained from the UAS, and also to get feedback on the perceived suitability and practicality of the data obtained. Palys (1992) outlines several ways for gathering data using contact and response methods. Since our goal was to develop an engaging discussion with the grower and understand their needs from a UAS, I used a direct contact and response method. I made my own objectives clear to the grower through a non-disguised measure as mentioned by Palys (1992). It was concluded that an interview would be most appropriate for these research purposes as interviews generally have higher response rates and allow for more in depth questions than questionnaires (Palys 1992). The interview with the apple grower was designed around a community design charrete. Traditionally, community design charretes are conducted by planning officials who invite community members to help discuss and identify a variety of spatial issues on local maps such as poor road infrastructure, pipe leaks, changes in local ecosystems etc. For the purposes of this project, I conducted a charrete with the two owner-operators of the study orchard and their lead orchard manager using a regular RGB image obtained from the UAS as a map of the orchard at first, then with the NDVI, CWSI and DEM imagery later.

Interviewers have also been known to consciously or unconsciously influence how the interviewee responds to questions (Palys 1992). The information required for this research did not lend itself to be simplified to a simple structured questionnaire. However, I took certain measures to prevent any influence on the interviewee such as not showing the images or analysis obtained from the UAS until later in the charrete, with the exception to the basic RGB image of which the charrete is conducted on. Because I wished to enter into a discussion with the grower, the advantages of the interview process outweigh the potential disadvantages. During the interview, including the charrete portion, I used a semi-standardized interview structure as outlined by Berg (2001). A standardized interview uses only a set of fixed questions while an unstandardized interview, the questions are developed as the interview progresses. A semi-standardized combines both elements with a standard set of questions but allows the interviewee to elaborate on particular thoughts and issues. I had a set of questions for the charrete and after the charrete but the charrete was more unstandardized as I asked the grower to draw or show specific parts on their field, elaborate on their concerns and to engage in conversation, particularly on the perceived usefulness of the data received from the UAS.

I used the techniques outlined in Palys (1992) and Berg (2001) on how to word, order, and communicate my interview questions, as well as creating a discussion with the interviewees. Prior to the interview, I explained the purpose of my research to the apple orchard owner(s), allowed them to ask questions, guaranteed their anonymity, and assured them that all of my findings will be available to them. With the permission of the grower, I took notes to record the interview including the charrete. During the charrete I asked the grower to identify and draw areas where crop harvests are plentiful and low, healthy trees and unhealthy trees, general irrigation patterns for the field, as well as general elevation of their field. These were being conducted with markers by the grower on the map to ensure simplicity for the grower. It was assumed that the grower will be familiar enough with their own field that they will have enough orientation to provide this information on a simple colour map of their field taken via the RGB camera of the UAS. These simple drawings were then be compared to the image results obtained from the UAS from which the grower and I discussed similarities and differences between the two and to draw out any further questions. From this charrete I conducted a series of interview questions to stimulate a conversation into the usefulness of the information presented to them in the images is useful, what would make it useful, and how they would want the information to be obtained. Based on these comparisons we discussed the following: Why such differences or similarities occurred? How much of this information regarding the CWSI, DEM and NDVI patterns on their field did they already know and did not know? Would an image displaying the CWSI, DEM, NDVI and/or the relationship between these be useful piece of information during the growing season? What would make this information more useful? A full list of the interview questions can be found in appendix B.

4.6 Challenges and Limitations

There were certain challenges and limitations that must be acknowledged for this research project. Most of these challenges will revolve around the UAS itself. UAS technology is a fairly new, with different control mechanisms used for different UASs. Although I am familiar with piloting UASs for research purposes, I still required time to learn and practise piloting and creating flight paths for this particular UAS. In addition this required time to develop optimal flight altitude for scanning the farm fields. Developing the optimal altitude also required some trial and error. Additional batteries for the UAS were also purchased to maximise flight practise.

One limitation with this study was the use of the CWSI to measure water stress in the orchard. The thermal sensor can pick up thermal radiation from the ground and cause interference from the readings of canopy. In addition, the rough nature of the apple tree canopy can lead to small air canopy differences and can possibly result in CWSI values greater than zero even for well-watered canopies (Osroosh, 2014). The CWSI also relies on the physical responses of the stomata. In apple trees, the stomatal conductance is a function of load and reduces as the load decreases which increases canopy temperature (Lakso, 2003). Because the non-water stressed baselines of apples are dependent on load as a result, they might not reach a CWSI value of zero for a well-watered tree with a low load.

The unfamiliarity of UAS technology to the public can attract curious onlookers during this project. UASs and UAS's are very topical subjects in the media ranging from issues in the military, air traffic safety and privacy. Although this project did not involve any of these issues, there was some small concern that public onlookers may be misinformed or make assumptions about the project based misinformation form the media. However, the rural location of the research made it unlikely to attract public onlookers and the growers informing all employees of the flight with the necessary safety precautions taken. Like any aerial vehicle, the UAS could cease to function in mid-air and crash. This occurred during the first flight of the study, with the repercussions explained in further detail later.

Curious people are not the only thing UAS's attract. Past experiences flying UAS's have shown that certain species of territorial and predatory birds such as the red-winged black bird will attack the UAS. Red-wing black birds are known to be territorial and will even attack larger birds (Terres 1980). Past experiences while flying UAS's have shown that these birds can mistake UAS's as a rival intruder and attack it. Numerous videos online have also shown a variety of birds attacking UAS's mistaking it as a rival or prey. However, such attacks rarely cause severe damage to the UAS, and simply require the UAS to land and wait for the birds to pass. Luckily no wildlife attacks were encountered during the process of this study.

Weather was a major limitation for this research as flight practise is semi-dependent on clear sunny weather. As mentioned earlier, the UAS flew only on a clear sunny day in order to obtain quality data. Low winds ensure a stable platform for the cameras, and a sunny day helps ensure that the thermal camera detects the best spectral response from the plants below. As described in the methods section flights with the UAS will were planned around local weather forecasts. However, despite this, weather became a major issue coupled with timing during this study.

While the UAS is durable and requires little space to operate relative to a manned aircraft, it will still require a safe area to take off and land. This requires a small open grassy area, with no tall vegetation such as trees and large cornstalks, telephone poles or wires, or roads nearby. This required us to limit which study sites we use during the flights. Alex MacLean of the depart of Geography of Wilfrid Laurier University loaned the UAS for this project, and as such ultimately determined if the study site provided a safe location for landing.

The results of my research are also limited as I am only interviewing one apple orchard grower in Ontario. Apple growers in other parts of Ontario and across the country may employ different management practises that could affect the correlation of the DEM, NDVI and CWSI values. They may also have different priorities and opinions and the usefulness of the data being given to them and on UAS technologies for agriculture. Because of this, these results should only be generalized to Southern Ontario.

5.0 Description of Study Site

All flights for this study took place at the Pine Farms Romeril Apple Orchard. The Romeril orchard is a small 16-acre orchard that operates mainly as an agriculture tourism operation, primarily using their crop and sites as a pick your own apples experience, educational tours, and produce for their own on site cafe. Some apples are also shipped to local farmers markets and grocery stores for commercial purposes and collected by hand. The 16-acre farm ranges from 298 - 320 feet above sea level with the highest portions in the north and centre of the field, and slopes and low points on east and south west. A full DEM map of the field can be viewed in figure 11. On average, the orchard is able to produce 140-150 thousand pounds of apples in single season. While the owners have received no formal education in agriculture (aside from a few local college courses), the farm has been in the family for generations, and the owners have extensive firsthand knowledge of their crop and land through first hand experiences, and are also members of the Ontario Apple Growers Association. The orchard does occasionally use external services for informational data on the orchard, such as plant analysis and soil analysis approximately 1-2 times a year. However, this is often done by a chemical company representative with the owners feeling that they sometimes over exaggerate threats or conditions in order for the owners to purchase their product or service.

Figure 9 below shows some examples of thick and thin rows on the orchard. The thinner rows are populated by saplings and were in some cases to small to be picked up by the thermal camera as a pixel.

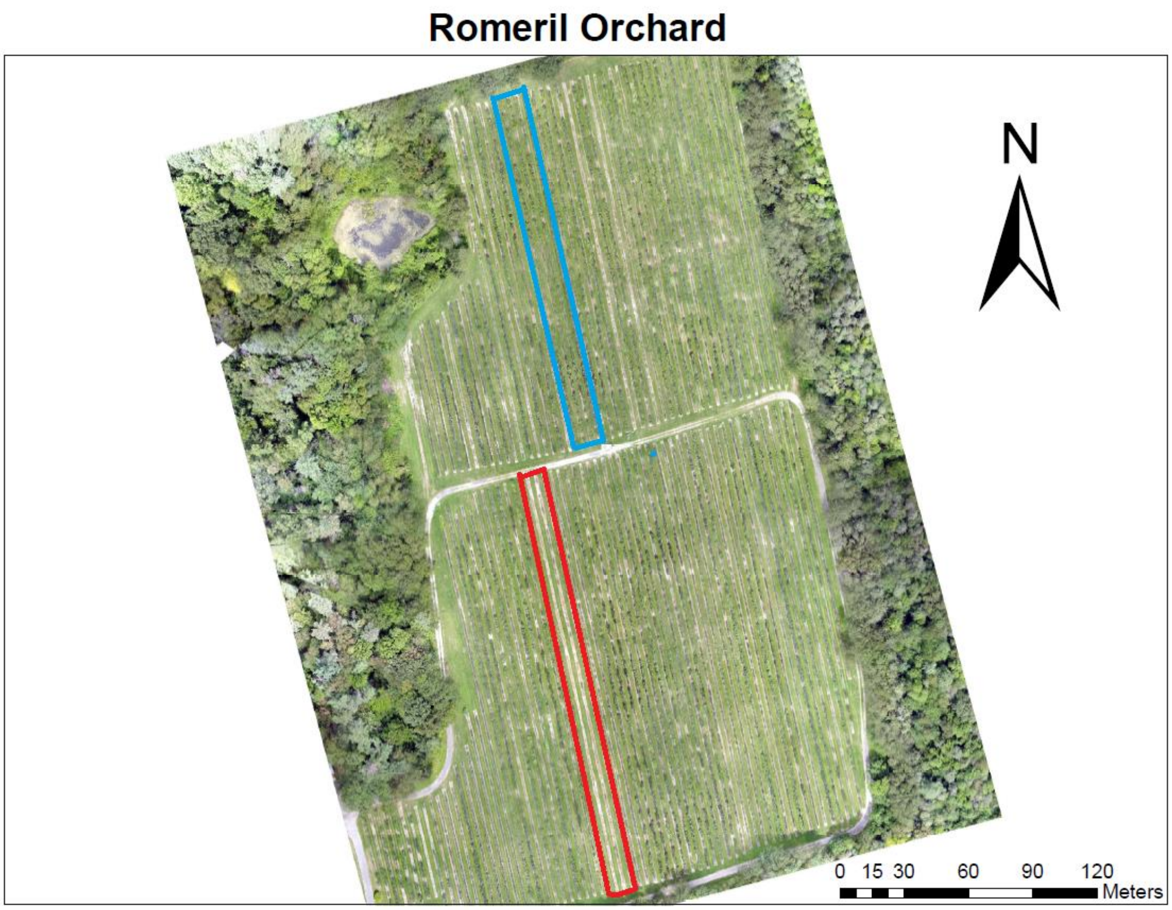


Figure 9:Thick (Blue) and Thin (Red) row examples. Notice the thick row is almost all green with no visible soil beneath it, while in the thin rows, only the soil is visible with little green from the trees.

Several individual rows were tested for CWSI and NDVI analysis to determine if there were any correlations or patterns that appeared in certain crop varieties or geographical location, however no patterns or correlations other than the ones found for the entire field were discovered. The locations used are shown in the figure below.

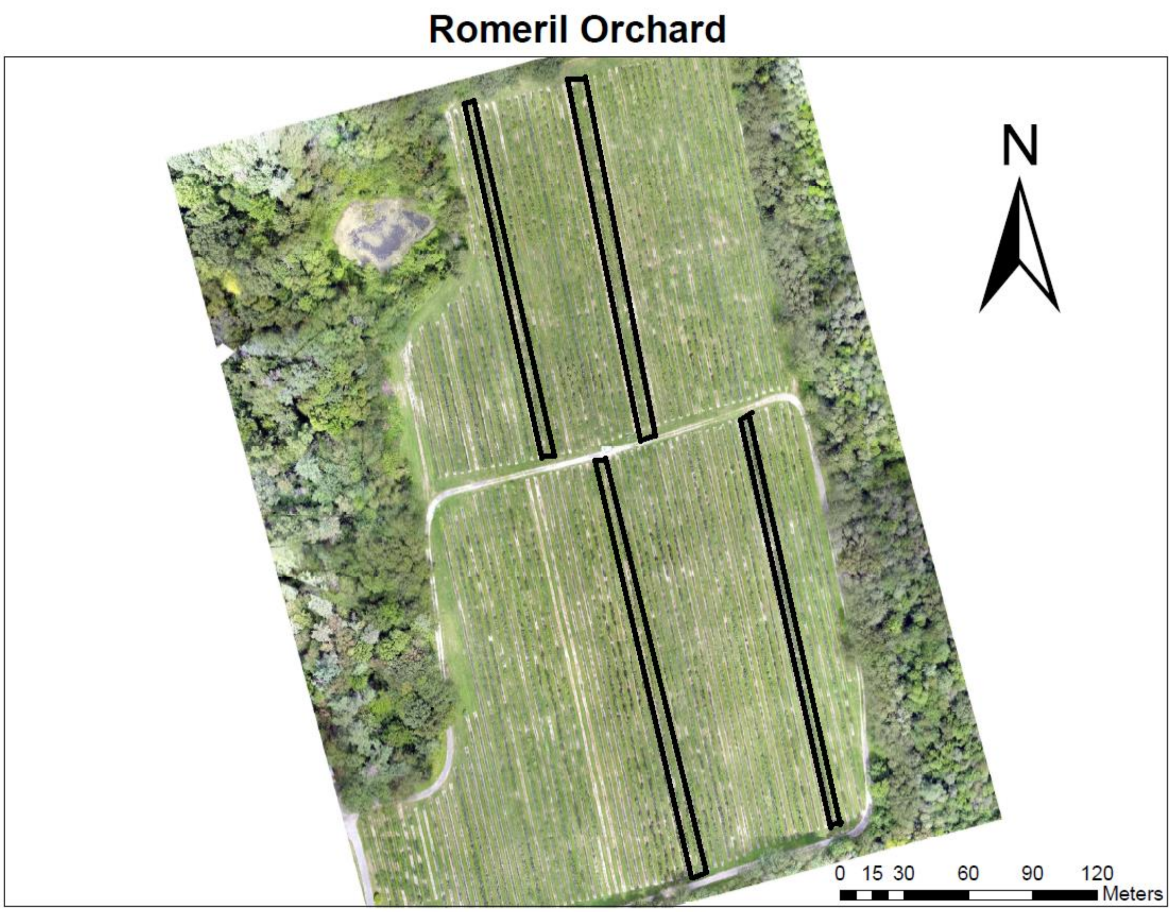


Figure 10: Examples of individuals rows used to test separate CWSI and NDVI analysis. Scatter plots comparing these values were created however no different patterns or correlations were found then with the entire orchard (see discussion at pages 54 and 55 below).

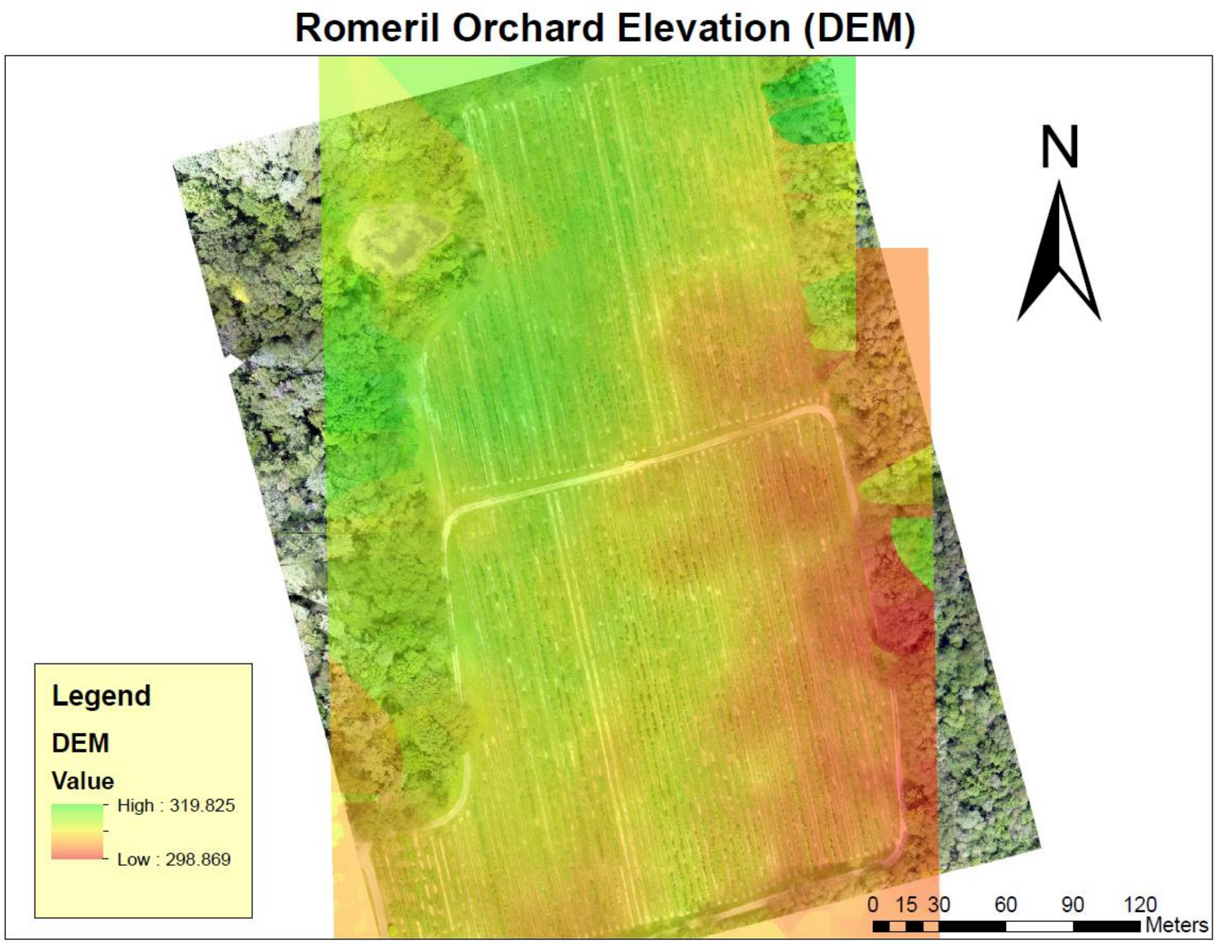


Figure 11 A DEM of the orchard. The orchard is higher in the north and slopes in the west and south east

In terms of farm equipment, the owners believe that the most important piece is the tractor as it is the primary workhorse of the farm, and is used with various attachments such as the flyer and sprayer ($40 000 in total). Other pieces include the mower ($8000) and the fertilizer/ spreader ($20 000). All these pieces often work in tandem with each other and produce tangible results for the farmer. But they require large investment and seriously impact the profit margin of the farmer if one was to break down, especially during key points during the season.

While profit the main concern when making management decisions on the orchard, environmental concerns also play a chief role in farm management strategies. While maintaining a strong environmental standard in their practise helps preserve the "traditional farm" aesthetic for drawing in tourism, the owners personally believe that they have a social responsibility to maintain a high environmental standard in their practise. This is seen in the owners’ reluctance to overuse pesticides/herbicides on the farm, maintaining the property as to not interfere with the neighbouring protected forest (Happy Valley Forest) and hosting the farm for numerous student educational tours on geography, environment and sustainable agriculture.

The main concerns for their orchard include apple scab, fire blight, mites, and spring freezes. Apple scab is one of the chief concerns as while it does no major harm itself to the crop, it makes the apple unappealing for consumers and is difficult to detect or prevent until an outbreak without the use of heavy pesticides/herbicides, something the owners find very unappealing to use due to health and environmental concerns.

This crop season saw some outbreaks of mites and fire blight in the orchard, and while they were not detrimental, and quickly taken care of, it is always a great concern for the owners since if left unchecked these pests can ravage their entire crop. The owners admit that they are only able to detect these outbreaks early on due to the small size of their orchard, and even with the small size pests can be difficult to spot before they spread.

Spring time freezes are also a major issue for the orchard owners. During this past crop seasons alone, the owners lost nearly 50% of their own crop due to cold snaps and freezing rain in the spring. While this is an issue that mainly threatens saplings and younger trees, this past season it also destroyed some full grown plants by cracking their trunks. The owners can prevent this by spraying the crops with water to keep them warm, but it is expensive to do this, and difficult to assess as they lack canopy temperature information of when to do this.

6.0 Results

Image result maps of the DEM, NDVI and CWSI indices as well as a plain RGB maps showing examples of thin and thick rows of the field can be seen in figures 12 through 13 below.

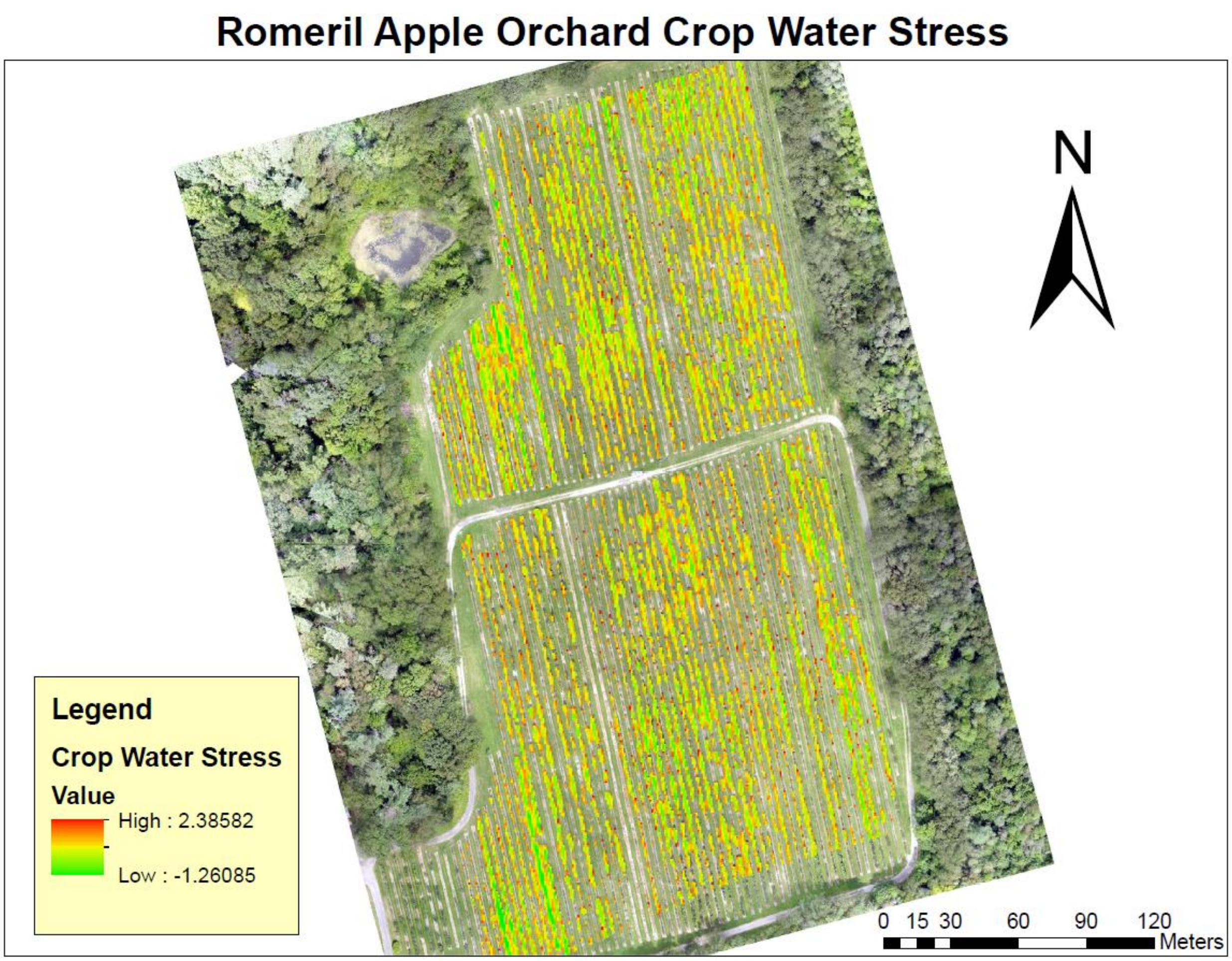


Figure 12: CWSI of the orchard. The CWSI analysis showed that lower CWSI values appear somewhat more in the north and south west portions of the orchard

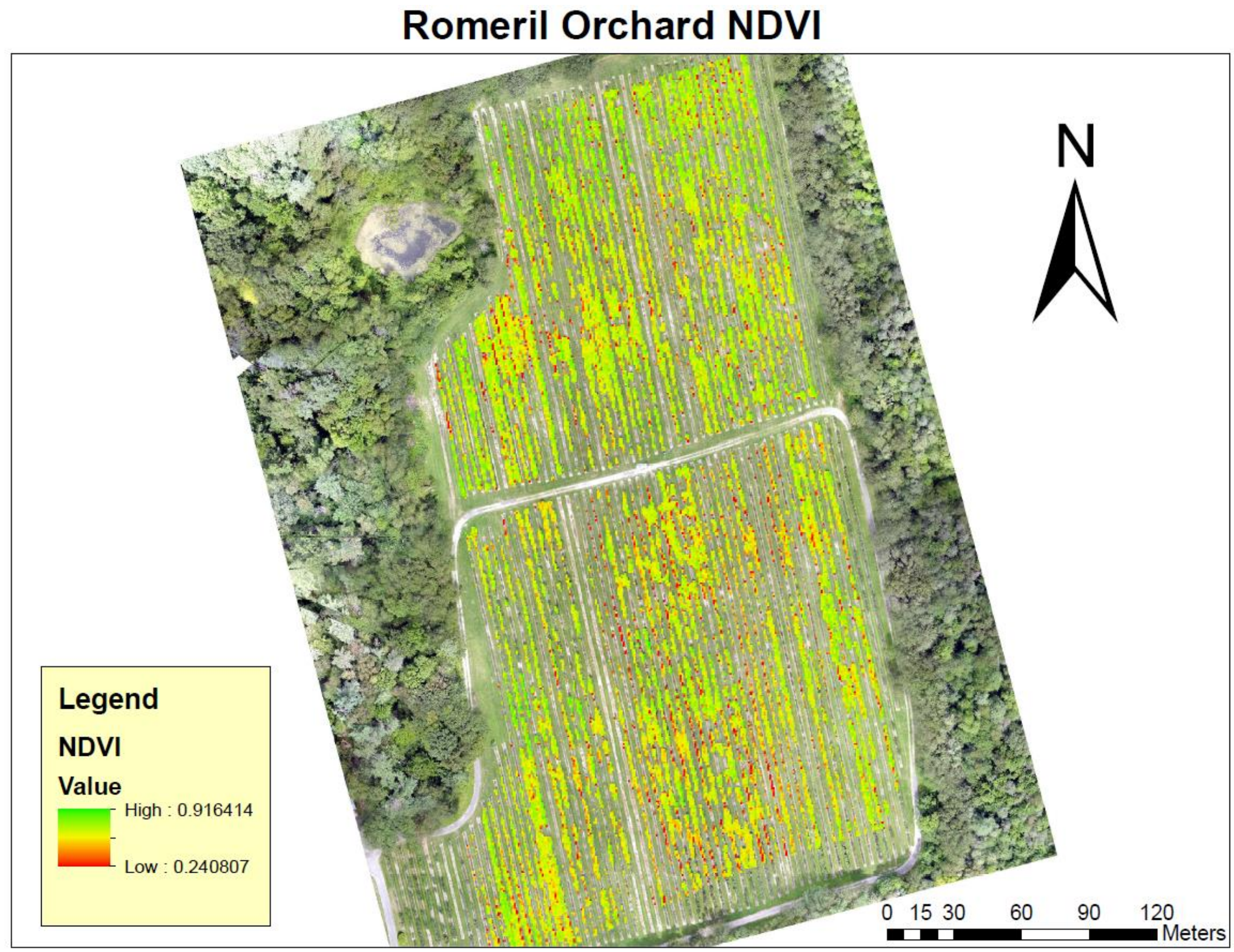


Figure 13 NDVI of the orchard. From the NDVI analysis, values appear to be higher in the north and east of the orchard, with the lowest values clustering in the central-south portion and the north-eastern corner.

The results of the CWSI analysis (Figure 12) show a range of values between -1.26 and 2.38, which are well beyond the normal range of values which typically range between 0.2-0.8. However the intent of this analysis was never to achieve precise empirical CWSI values, but instead was intended to compare relative values within the same field. There are numerous potential sources of error in these results. As shown in figure 9, certain rows are thinner than others, exposing the soil and grass beneath the trees. Both the soil and grass had warmer surface temperatures than that of the apple tree canopy, in some areas up to 7°C warmer. An example of this temperature difference can be found between the thick and thin rows shown in figure 9. Due to the low pixel resolution of the thermal camera and the higher than anticipated UAV flight, these soils and grass can be mixed in with the apple trees in the same pixel. Because the mask used was based on canopy temperature, this could have included some of the soil from beneath the trees, particularly along thinner rows and grass along the edges of thicker rows, leading to issues of mixed pixels. The UAV was also flown on a cloudy day, which is not optimal for calculating CWSI, as the clouds will make for a cooler apple canopy temperature and a cooler air temperature at ground level. Despite these sources of error during the data acquisition, the CWSI values still showed a relative and comparative difference in crop water stress within the overall orchard. This pattern can be seen in Figure 12, with the CWSI appearing to be lower in the interior of thick rows, with thickest rows of trees having the lowest CWSI pixels. The edges of these rows always having a higher CWSI that increases the further it is from the center of the row. Due to the height of the drone in flight and camera resolution, certain rows that were predominately made of saplings did not show up during the analysis. The results of the CWSI analysis showed that lower CWSI values appear somewhat more in the north and south west portions of the orchard. The results of the DEM analysis show that the highest points of the orchard are on the north and north-west portion, with the south-west and east having the lowest portion, with the south-east having steepest drop. The results of the NDVI analysis range from 0.24-0.91, which are values typically associated with NDVI analysis. From the NDVI analysis, values appear to be higher in the north and east of the orchard, with the lowest values clustering in the central-south portion and the north-eastern corner.

Figures 14-16 show the correlations between the CWSI, DEM and NDVI values.

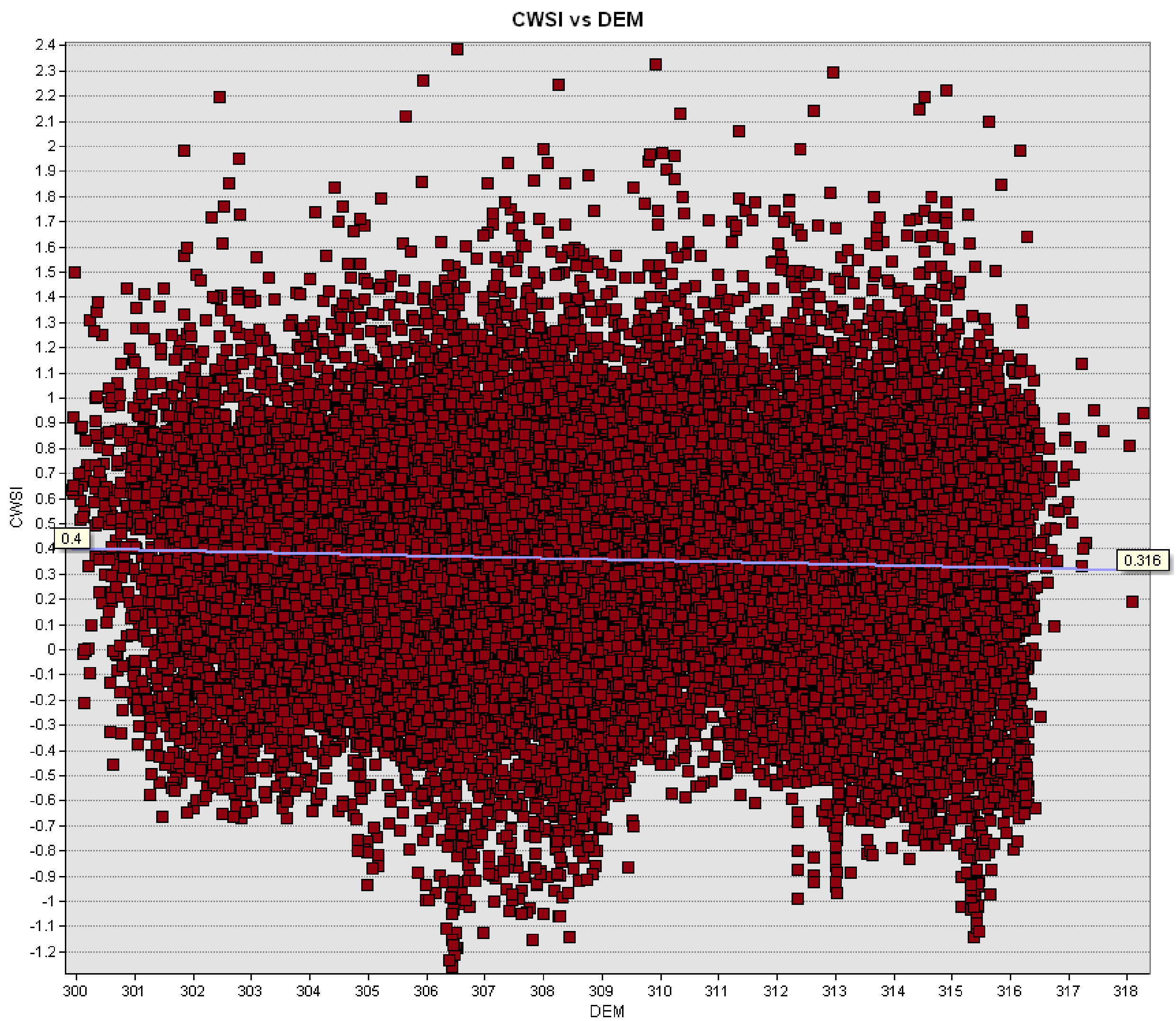


Figure 14: CWSI vs DEM, this shows that there was no correlation between the DEM and NDVI values

A scatter plot of DEM and CWSI values in figure 14 shows no correlation the two values, with most value relationships appearing to be random.

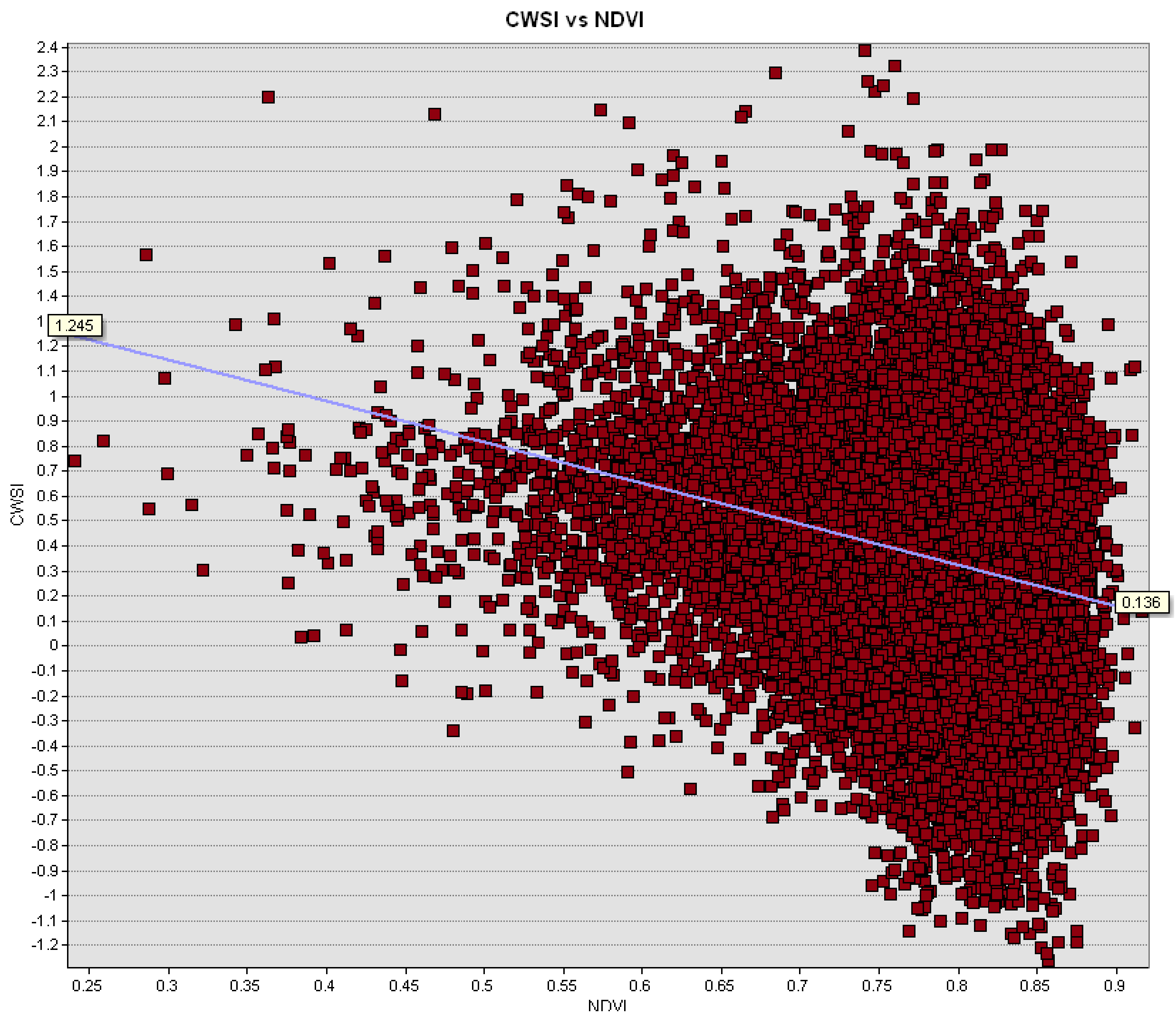


Figure 15: CWSI vs NDVI, which shows that there is a correlation between CWSI and NDVI values. While the CWSI were not empirically accurate it does so a relative accuracy as well watered plants are likely to be healthier overall. However, there are numerous other factors that can lead to high NDVI values and some inaccuracies in the CWSI.

While the relationship between CWSI and NDVI values does appear to be somewhat random, there does seem to be a slight negative correlation between the two values, showing the lower CWSI contributes to a higher NDVI. This can be seen in the graph of figure 15 as the very lowest CWSI values are also some of the very highest NDVI.

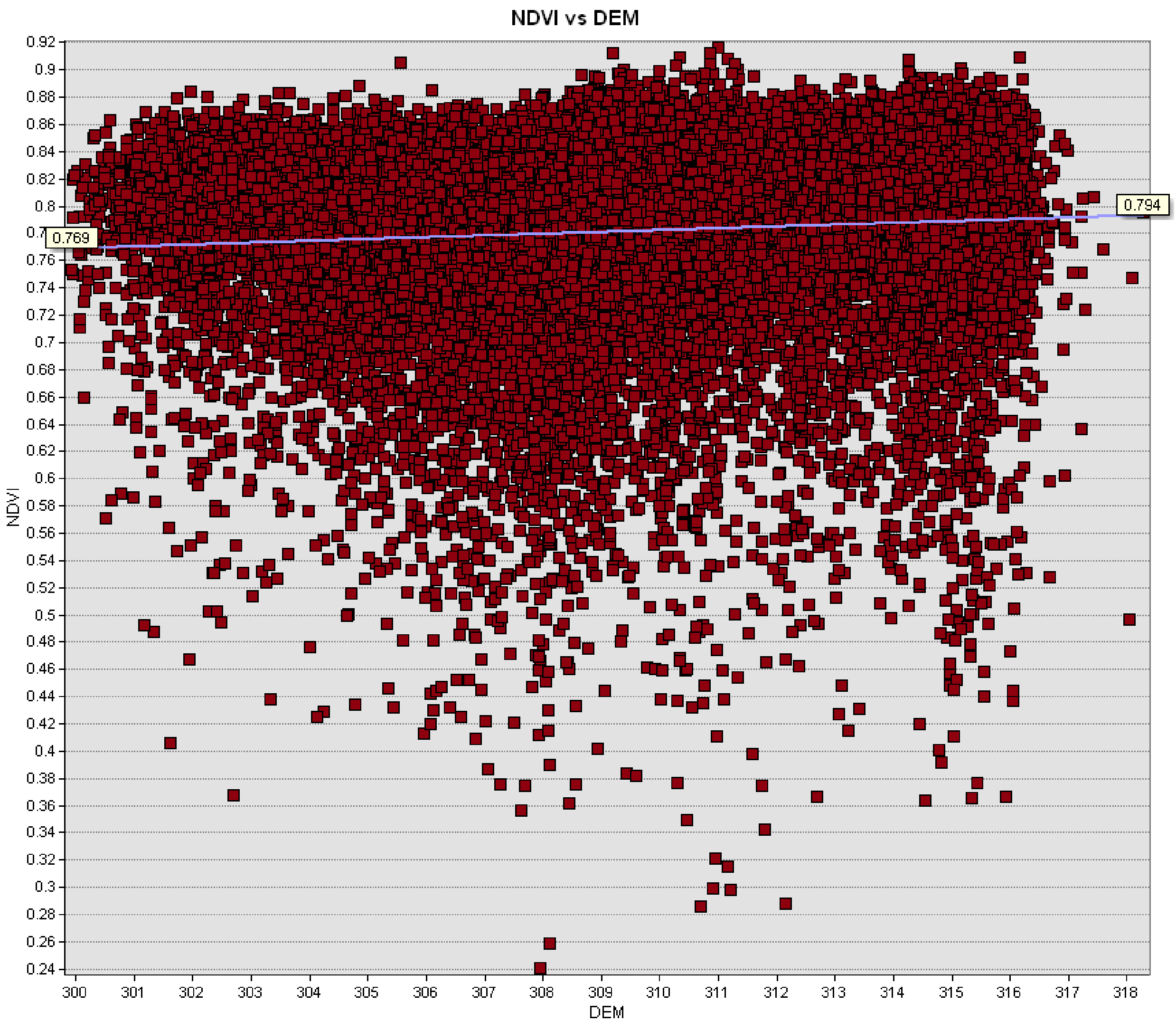


Figure 16: NDVI vs DEM, this showed that there was no correlation between NDVI and DEM values.

The relationship between NDVI and DEM values seen in figure 16 shows no correlation between the two, with high NDVI values found regardless of the height of the orchard. Scatter plots comparing these values were created for the selected individual rows shown in figure 10, however no different patterns or correlations were found then with the entire field, eliminating the possibility of variation between apple variety. as trend lines for the scatter plots showed values nearly at zero. Canopy temperature was the only value when calculating the CWSI that was not a constant for the field. Because of this crop canopy temperature was also compared to the CWSI to estimate if farmers and growers could simply use crop canopy temperature to estimate CWSI on their own. The results on the orchard are shown in figure 17 and the results compared to CWSI values shown in figure 18. These results show that while the crop canopy does follow some similar patterns as CWSI it is a weak correlation, meaning that crop canopy on its own should only be used as a very rough estimate for crop water stress.

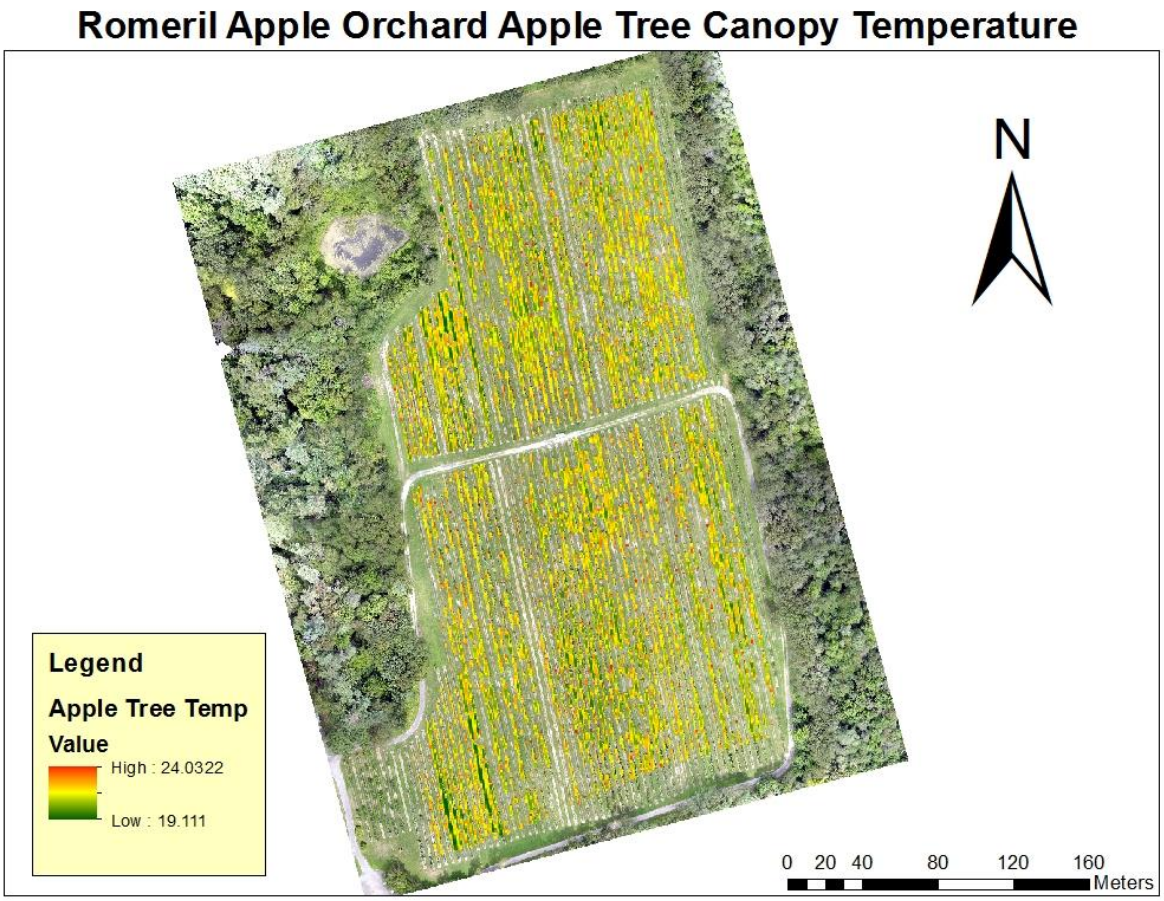


Figure 17: Crop Canopy Temperature on the orchard

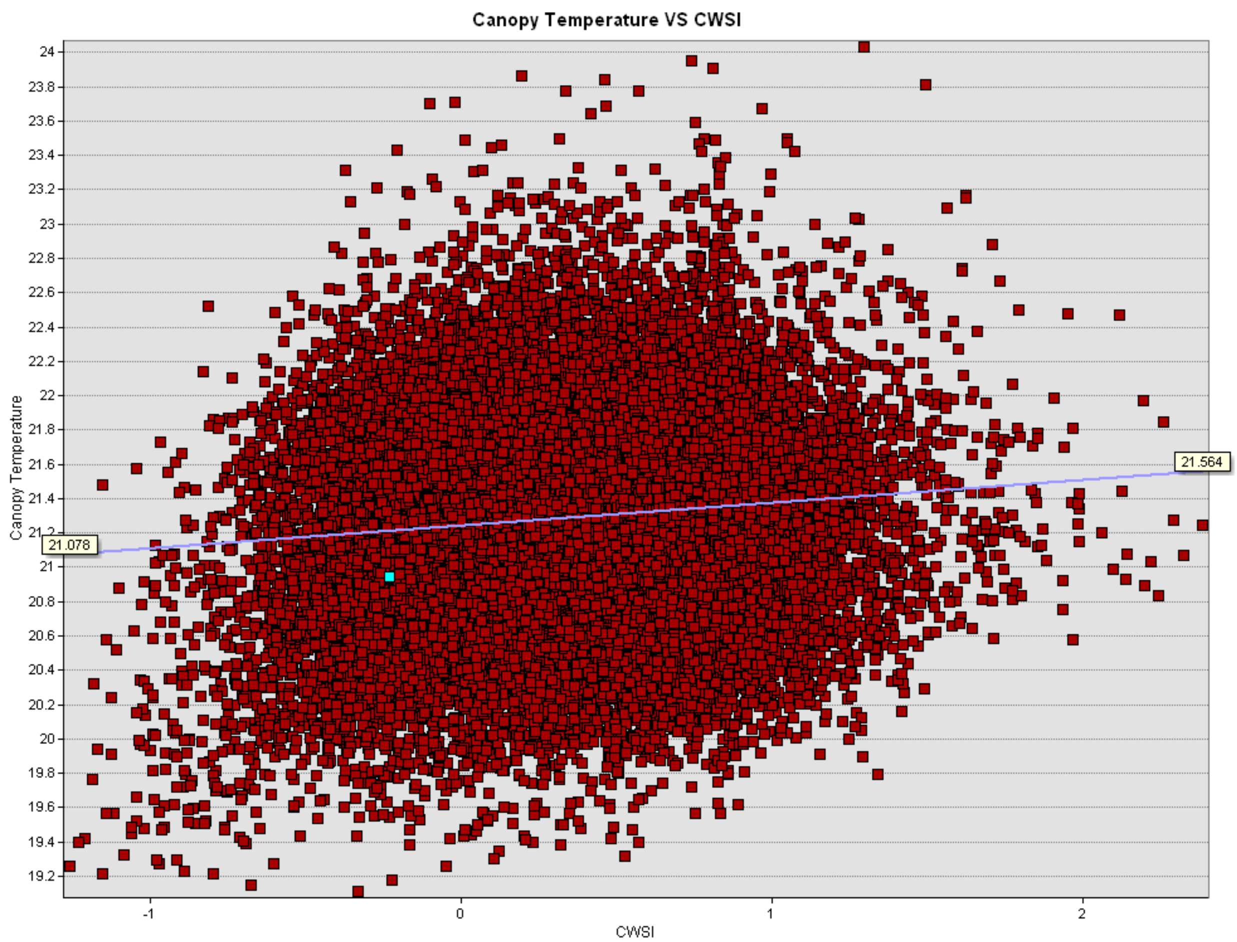


Figure 18 Crop Canopy Temperature VS CWSI data points. This figure shows that while there is a correlation, it is weak and shows that crop canopy temperature can only be a very rough estimate for crop water stress on its own.

The VPD baselines of this study aligned with those acquired from Păltineanu et al (2010). The recorded air temperature of 22 °C and a relative humidity of 76% showed a VPD of 0.6 kPa, which would but it at the upper end of their baseline chart, meaning that CWSI values calculated are much lower than they actually are. In Păltineanu et al (2010), a VPD of 0.6 kPa would normally be obtained at around -2 dT. In this case it is likely that the air temperature is much cooler than what would be optimal environmental conditions to accurately calculate the CWSI, showing that the largest cause of error in this study was likely the cloudy conditions during which the air and canopy temperatures were taken, leading to cooler temperature readings.

Written responses to the interview questions and charrete can be found in Appendix C. Before being introduced to this study, the owners had heard of UAS's being used in agriculture but only in cash crop fields had limited information of its applications. When asked about what they believe current UAS's could show them of their field, the owners explained that it could likely easily show them in their orchard are patches or barren pockets, saying that this would particularly be helpful in larger orchards. Ideally however, the orchard owners would want the UAS to show them maps of the soil moisture of their field, and the crop canopy temperatures as this information would help them better plan for spring freeze issues and locate areas in need for irrigation based on the crop canopy temperature.

While they stated they would be interested in utilizing a UAS into their orchard management practises, they do have some concerns regarding the cost benefit of utilizing a drone, and prefer to hire or employ a service to fly the drone for them due to the costs of buying a agriculture drone and the costs/time needed for the skills to fly and analyze the data.

When presented with the images and maps the orchard, the owners and employees were instantly able to recognize the map, identify features, and understand the data being shown to them with minimal explanation. Instantly they were able to identify reasons why certain areas had low NDVI or CWSI values. This instantaneous connection with the data showed that while the data can be seen as irregular or random to those unfamiliar with the field, those who work on the field and know it will can read and interpret it with ease. While showing the standard RGB map but before being shown any of the DEM, NDVI and CWSI maps, the owners and employees were asked to draw in the elevation/topography of their farm and identify any general issues or problem areas they have encountered this season. When identifying the topography of the orchard, the employees were able to draw and describe hills and slopes that were extremely close to those found in the DEM results. They noted the high plateau in the north, the lower parts in the east and south west and the ridge between.

When identifying problem areas, the owners noted issues of dry plants in the central parts of the northern section of the orchard, and in the east of the southern section. In addition, they noted an outbreak of fire blight in parts of the north-west and south-central portions of the orchard, along with some problems of apple scab in each of these areas as well. The orchard experienced frost damage in the early spring along the southern corners of the field and in the north-west corner as well. The owners contemplated that this frost damage may have weakened other trees in this area that did not die, allowing them to develop issues of apple scab and fire flight that occurred in these areas as well. In addition they believed that this also contributed to issues of leaning stress amongst some of the older trees in this area which performed poorly this growing season when compared to others. Along many areas in the south central portion of the orchard, the owners noted that they had some issues with the herbicide not taking full effect there, with some other plants possibly choking out the apples and absorbing nutrients intended for the crop. The owners pointed out that the best growing areas are in the northern portion of the orchard along the high plateau as they claim they get access to the most sunlight, and also have noted areas to do well traditionally in the western midsection of the orchard.

When presented the results of the CWSI map, the owners first observation was that while the results follow patterns that they are familiar with that occur in their orchard, it seems to be somewhat random in other areas. The noted that low values of CWSI in the North West corner as it coincides with the various issues with fire blight, and frost, all which have a greater impact on younger trees which occurred in this area. More information was explained to the owners that the images were taken during late August and that the equation used in this study assumes that as a crop transpires, the evaporated water cools the leaves below that of air temperature. Thus, as the crop becomes water stressed, transpiration will decrease, and thus the leaf temperature will increase. After understanding this, the owners noted that in apple biology during and just before harvest season, apple trees focus much more water content into the apple fruit, rather than the leaves, which will cause irregular transpiration in the leaves. Stating this could be one of the sources of the random nature that the CWSI that appear on this image.

7.0 Discussion and Recommendations

7.1 Challenges Encountered in Capturing and Manipulating Data

During this study, long processing times ranging from 3-5 hours were experienced when creating an orthomosaic image of all the pictures taken by the drone. Although the time needed to process the images depends on the power of the machine being used, this study experienced these long times for a mosaic of a 16 acre farm (relatively small). In addition, our computers were prone to crashing during the thermal images, requiring us to restart the mosaic process. So much were programme crashes a problem, that processing for the thermal images had to be transferred to another computer in order to mosaic a thermal image. To mosaic a larger field such as a 100 acre - 500 acre commercial farm would require a substantial longer time and may be more prone to crashes.

These long processing times may make it difficult for large farms to have timely information, and would require further testing to streamline the process, but it is still entirely doable. Alternatively, farmers may only select flights over specific patches or trouble spots to get the data to ensure more timely data and easier processing/acquisition. This may also be the case for obtaining higher resolution data. As flying at heights to obtain the entire field in one flight may not achieve the resolution needed to accurately see the field or perform algorithms. One of the initial goals of this project was to try and determine if apple counting would be possible from a drone. This was impossible at the resolution obtained from the images, but may be possible with extremely high resolution images or lower flying air craft. If this would be the case, then more time flying and processing will need to be done for the entire field, as well as more resources (i.e. more batteries to interchange immediately). This can take even longer and be more demanding since more sensors would also need to be interchanged between each flight. Again, this is why farmers may choose to fly over specific portions or trouble spots in order to obtain the information in a timely fashion and at the needed resolutions.

Many logistical and technical issues arouse during this flight. Under Canadian law, UAS's used for commercial or research purposes require the application of a SFOC (Special Flight Operations Certificate). This is a complex and long application that would be very difficult and time consuming for someone who is unfamiliar with to fill out and file. In addition, flights cannot be conducted until the application is approved by Transport Canada (TC). This process can sometimes be extremely lengthy or get lost in bureaucracy. In the case of this study, a second study area was chosen with a SFOC written and sent to TC. While this process would normally take 2 weeks for a response or approval from TC, the application was not approved until approximately 2.5 months after the application was sent, long after the growing season and during the harvest, making the approval useless and the study site lost. Canadian law states that the UAS pilot should also have experience with piloting UAS's. There is currently no standard on what counts as "experienced" nor is there a nationally recognized training course or certification, and experience assessment is subject to the reviewer on the SFOC. While this was not an issue in this study, it may become an issue for farmers who wish to conduct flights on their own property or for a service company that is just starting up. Canadian law also requires a second ground observer with some experience with UAS's to also be present at the site when flying. If an orchard/farm or company would conduct these flights, they would require two employees during the flight. This would require the time, pay and travel for each of these employees, and logistics of working around two personal schedules, which can be further complicated by internal company bureaucracy, all issues that was encountered during this study.

Mechanical problems are another issue. During the study, a mechanical failure was encountered during the first flight that left the drone completely unresponsive. Because of this, we had to wait another 3 weeks for the drone to shipped, repaired and shipped back, which left us time to only fly towards the end of the growing season. While the UAS was sent back to the company for repairs in Switzerland, a temporary UAS was given to us as a loan by the distributer. This model however was unable to use the thermal sensor and so only flights with the NIR and RGB sensors could be made. By the time the original UAS model had been repaired and returned to us in the middle of August, the apple growing season had nearly ended, with the harvest beginning soon.

Weather is another crucial issue when flying UAS's. Under Canadian law, as general safety, protection of equipment, and in order to obtain good data, the UAS should only be flown during daylight hours on clear days with little wind. Trying to schedule a flight while accounting for weather extrapolates the logistical issues of personal scheduling and bureaucracy previously noted. This can make scheduling difficult as there may be times in which a flight day and time is agreed upon for all parties, only for it to be cancelled due to unforeseen bad weather, while during days of optimal weather only one or none of the parties may be available to attend. Both of these situations occurred numerous times during the course of this study. In this study scheduling for a flight date had to not only account for weather but also needed to occur during a time frame that would work for both the personal and professional schedules of two University students/employees who were already busy with their own research, to accompany the drone (as stated in TC UAS law that all flights must be accompanied by two individuals). The schedule of the orchard owners also needed to be considered.

Because of the time constraints put forth by these logistical and technical issues, this study forced us to find a day and time that worked for all parties and fly during any conditions that allowed flight in order to gain some semblance of data. Because of this the CWSI flight was conducted during a cloudy day, in which environmental conditions not ideally suited for such data gathering and would likely lead to some data error. These are all issues that will likely be faced by farmers conducting their own flights or by companies contracted to service these farms.

Often, CWSI equations assume that the crop canopy completely covers the soil surface. This was not the case for this study as other than the thickets trees, many of the apple trees did have soil background, particularly the younger trees. A soil background included in the surface temperature measurement can lead to false indications of water stress, as a dry soil is often much warmer than air temperature. This issue itself could be one of the major factors of why some of the CWSI number came up high and even above 1. Regardless, the pattern and layout of the apple trees mean that there was grass between each of the trees. This grass also came up as predominately warmer on the thermal camera, and could also have created issues of background noise to the trees similar to that caused by the soil. It was hoped that the camera resolution of the thermal camera would have been high enough to easily differentiate between the trees and other background noise or at least mask out the apple trees. It is also possible the apple trees were simply not thick enough to prevent any back ground noise as they are just in rows and that even with a mask it would only reduce the background noise but not eliminate it. With the low resolution of the thermal camera, it is possible to have a camera flown closer to the surface to achieve greater detail of the trees. However, in this study because a fixed wing air craft was chosen, a minimal altitude is needed for the UAS to operate properly and take pictures. During the mission, this UAS was already flying at the lower limits that its automated programming would allow. While flying at a lower altitude is certainly possible, there is a safety risk of the UAS possibly flying into other trees as it could risk going below the tree line of the surrounding trees. If a lower flight altitude is desired, then it would be more applicable to use a quad copter style UAS that would allow greater mobility over the field at a lower altitude. Regardless of which aircraft is used however, the lower altitude would require more pictures to be taken and processed in order to put together in a mosaic. As mention earlier, this study was conducted only on a 16 acre farm. However images from even this relatively small farm already took several hours to process/mosaic, and the computing was still prone to crashing when processing thermal images. This was all from a UAS flying at a height that is normally reserved for larger farms of around 100 acres. Flying at a lower altitude and on a larger farm would drastically increase the possessing and mosaic time, and increase the flight time and battery usage. While this may greatly increase the effectiveness of the cameras, this may not be a practical alternative to some growers who are already well versed in traditional methods, and therefore dismissive of the added time required to learn or understand the technical expertise and associated costs with remote sensing.

In this study, the resolution of the thermal camera was high enough to enable a mask to be created from apple trees and non-apple tree features. However, using a mask based on the crop canopy temperatures was chosen only because it was the most consistent in differentiating between apple tree and non-apple tree features when compared to the other sensors. While the NIR and RGB band values could easily give different values for vegetative and non-vegetative features (soils and roads) they had difficulty differentiating between the apple trees and the grass between the rows as all the values were too similar. While the thermal sensor was mostly consistent, there were some areas in which some cooler patches of grass were included into the mask, particularly in the north-west portion of the orchard.

Another possible and most likely source of error in the CWSI was the environmental conditions present during data was acquisition. The time that measurements are taken to determine crop water stress is very important. During the night, water in the soil has time to become redistributed around the roots, so in the morning the plants may show no signs of water stress even if the soil moisture reserve is very low. Therefore, it is best to take measurements in the afternoon, ideally at the same time each day. Additionally, under cloudy conditions, crop water demand is low, and again, the crop may show no signs of water stress. The crop canopy temperature data acquired for this study was captured during cloudy conditions with only some breaks in the cloud for sun. While these were not ideal environmental conditions to acquire the data, it was necessary due to the time constraints induced by the logistical and technical issues as explained before. These conditions likely made water demand for the crop very low and could have resulted in the low and negative values obtained during this study. The VPD baseline of 0.6 kPa, put it at the upper end of Păltineanu et al's (2010), baseline chart, meaning that CWSI values calculated are much lower than they actually are. In Păltineanu et al (2010), a VPD of 0.6 kPa would normally be obtained at around -2 dT, making is seem that the air temperature is much cooler then what would be optimal to calculate. This shows that the cloud cover creating a cooler air temperature likely caused a margin of error, or that a new VPD baseline would need to be created for southern Ontario apples due to the differences in climate between southern Ontario and southern Romania.

While the mask used in this study was fairly accurate in obtaining only apple tree pixels, it was not a complete success as it also included some pixels of grass and dirt. These pixels were included in the correlation analysis and as such could have been a source of potential error. In addition, the clustering of such pixels could also have given misleading information upon visual analysis, particularly when presented to the farm owners during the interviews, despite being made aware of the potential error source. Because the mask was based only on crop canopy temperatures, it is also possible that certain low or high temperatures of the canopy were masked out, although this is unlikely as temperature values identified were selected from apple tree pixel samples across the entire orchard. However, if a future study were to use this method or mask, the researchers would need to resample crop canopy temperature for their target crop across the entire field to find a temperature value to act as the mask. This method only worked in this study and may not work in others if the entire field has similar temperatures or the canopy of the target crop has similar temperature values of other crops or weeds. A future study could help identify a better mask for apple trees. Using a multispectral or even hyperspectral camera sensor may reveal more values to use as a potential mask for apple trees.

The baseline VPD values for apples used in this study could possibly be another source of potential error. VPD baseline values are available for many cash crops such as corn, wheat and rice. However, baseline values are not as publicly available for horticulture crops due to the lesser amount of agricultural and thermal research associated with them. In addition, VPD baseline values can change with the same crop in different areas of the world, particularly at different latitudes. In order to obtain accurate VPD baselines for a specific region, several different fields are needed with different rates of irrigation used in each one to calculate base stress values when the plant is well watered. Obtaining these values was impossible for this study due to time scheduling and the resources available. The only VPD baseline values found in a published article was Păltineanu et al (2010). Fortunately the VPD baselines calculated in this study were done in Southern Romania which has a comparable latitude with Southern Ontario, however because this study was conducted in a different continent, there may be other unknown factors that may affect the local VPD baselines causing them to differ with the Romanian values. A future study could conduct and create VPD baselines in Ontario, and compare it with the results found in Păltineanu et al (2010) to determine if VPD baselines are needed very every new location, or if indeed VPD values at similar latitudes can be used even in different continents.

Despite the numerous sources of potential error in the CWSI analysis, it is important to reiterate that the CWSI values are still relative to each other within the orchard. While not perfectly accurate in all parts of the field, the orchard owners did feel that CWSI results were consistent with their own understanding of their orchard. In addition, a correlation was found between low CWSI and high NDVI values, something that was predicted before study as a well-watered plant is likely to produce higher chlorophyll when compared to other plants of the same kind. Knowing the logistical and technical issues faced during this study, and sources of error for the CWSI, a future study could likely remove the majority of error sources, and likely show an even stronger correlation between CWSI and NDVI, and possibly obtain a majority of values that range within the CWSI norm.

Because the model designed in ARCmap uses a variety of inputs, in theory it can be used for any crop type on any UAS. A key component is that the user will need to manually input the target crops VPD baseline values, air temperature and humidity during the flight and the crop canopy temperature in °C that would be acquired through a thermal sensor. A future study could take this model and test it on a UAS that has flown over a variety of different crop fields each with ground control points that are ground truthed, and compare the accuracy.

Due to the technical and logistical issues mentioned earlier, there may be a source of error in the correlations between NDVI and CWSI due to each attribute being captured at different flights. Future flights should always have NDVI and CWSI flights back to back. This also reduces the chances for the need to use GCP in post processing.

The results of the DEM where consistent of the results observed on the field and were consistent with the knowledge of the growers. When asked to roughly draw the hills and slopes of the orchards before being shown the DEM, their results nearly matched the DEM obtained by the UAS. When asked about the necessity of DEM for their own practise, the growers stated that the data shows them something they already know quite well, being that they can already draw an image similar to the aerial image presented to them. However, the imagery did allow them to contextualize their own knowledge. Especially when used in combination with other data sets such as NDVI of CWSI as it allowed them to better identify issues presented in these maps that warrant a ground truthing and to better orient themselves to the locations where these issues are present in the field. For example, an identified troubled NDVI spot that would require further ground inspection overlaid with the DEM map could show it at the bottom or edge of a slope. Before this study, it was anticipated that the DEM values would form correlations with either the NDVI or CWSI values as the lower DEM values may pool more water in the orchard resulting in higher NDVI or lower CWSI. This was not the case in this study as all scatter plot graphs show that the results are completely random with both high NDVI values and low CWSI values appearing regardless of DEM values. One possible explanation for this is that the hills and slopes in this orchard are too gentle for it to have a major effect on water pooling. Another is that most of the soil located at the orchard is a sandy loam soil, which has high absorption rates for water. Relationships between NDVI and CWSI with DEM may only occur in more clay like soils as the absorption rates for these soils are much lower than sandy loams and would likely have more pooling effects. Regardless, it may also be possible that any pooling effects may not have any effects on the NDVI or CWSI values, as apple tree roots run very deep in the soil making them very drought resistant, and any water pooling effects would be negligible for such a deep rooted plant. Moreover, correlation may only be found on apple saplings or crops with shorter root systems such as corn or wheat. Further studies would be needed to confirm this possibility

7.2 How UAS Mounted Camera Sensor Would Best Benefit Ontario Apple Producers

During interviews with the growers, they stated that they would need the UAS to fly during specific days during the growing season. These days include early to mid-July for both CWSI and NDVI maps. In order for the UAS to provide timely data to the grower, they must fly during these days. This can be hindered by the aforementioned technical, logistical, bureaucratic or weather issues. Service providers may need to charge high prices in order to remain profitable when using expensive equipment in such a short time window for information. During the interview the farmers stated that they would pay $100-$500 per a flight, with a DEM only once. However for a NDVI and CWSI each year and in some cases multiple times within a single growing season, they may be willing to pay more. The growers admitted however that this cost would be only for their own field, and larger farms would likely pay more for their entire field, especially as the sheer size of a 100 acre or 500 acre orchard would not allow its grower to know it as intimately as a smaller field. With the growers knowing that NDVI is essentially a measure of the chlorophyll activity in the plants, they stated that it would certainly assist in finding potential trouble spots or other issues, and it would be used in conjunction to traditional methods to assist planning and not sublimit it. This is because chlorophyll activity is not always representative of the plants health or more importantly its crop potential, particularly in apples. NDVI has shown to be very useful in cash crops such as wheat or corn, but in these cases the entire crop is harvested with the fruit often bearing the majority of the plants mass. In apple trees, the fruit are a much smaller portion of the plants mass, and as such NDVI may not be as representative. The growers stated that in conjunction to NDVI, a methodology or sensor that can count the number apples in each row and give crop yield estimates would be extremely beneficial to them. A low flying quad copter or ground based drone using the methodologies employed by Wang et al (2012) could achieve the results needed by grower.

While the growers stated that CWSI is a useful attribute of information to have, crop water stress is not a major issue for apple growers currently. This is because apple tree roots run very deep into the ground and often are able to draw upon ground water reserves, and are quite resilient to all but the most severe droughts. However, this issue may become a larger problem as climate conditions in Ontario are likely become more prone to droughts due to climate change (Jenny 2012). Because of this, conducting CWSI analysis via a UAS could be a potential form of positive technological adaptation to changing climatic variability. Like many other issues however, crop water stress is primarily an issue for saplings and having timely is data on the sapling would be the most beneficial and practical. However, the results from this study showed that the drone flew too high and did not have a high enough resolution to obtain images of the saplings. The resolutions for the cameras used on the UAS for this study were already amongst the best available commercially, especially for the thermal camera. As such, it may be more practical to use a lower flying quad copter to fly specifically over rows of saplings to acquire CWSI.

As mentioned earlier a full CWSI analyses may not be needed as the growers may just need canopy temperatures to make their intervention decisions. This would also help in planning spring freeze prevention, as the growers believed that spring freeze was the greatest threat to the saplings, and having timely crop canopy temperature would greatly assist in the decision making needed as to when and whether to spray the plants. However, such an application with a thermal camera on a drone would need to be extremely timely as currently the decision is often made during late evening hours and on the spot. As such, it would be unlikely that such an application could be provided by a drone Service Company, and the costs needed to obtain the equipment and training may only be obtained by wealthier or large scale farms.

Smaller farms in co-ops however may be able to share the drone much in the same way they share other pieces of drone equipment, although this may be impractical to the extremely time and situation sensitivity of this particular application.

The other big threat that the farmers felt was a problem to their apple crop was disease, particularly apple scab and fire blight. The growers stated that they are always vigilante of fire blight in their field, removing trees at the first sight of it to prevent spreading across the orchard. Often it is the saplings that are the most vulnerable. Apple scab however, while it does little to physically harm the tree or fruit, makes the apple unappealing aesthetically to consumers and markets. This disease can potentially make the apples unsellable in their base form particularly for a "pick your own apples" business.

7.3 Best Options for Making this Technology Accessible to Producers

Both the farmer and service company personnel will face technical issues such as the mechanical failures experienced in this study, scheduling issues due to weather and professional/personal time commitments between the parties. Although it is likely the latter issue will be lessened as both personal will likely be scheduling their professional time around said flights. However, because flights are still required to have two individuals who both preferably have UAS experience under TC laws, this would require either the farm owner or service company to devote time and pay for two employees for each flight.

Flight timing however can be further complicated if it is being done commercially. An important point made by the orchard owners is that while the data acquired from the UAS is useful, it is optimal when received at specific times during the growing season. Ideally both a farmer and a service company would want to conduct flights during these times. However, these are small time windows, with the owners stating that for apples it is between early to mid-July, within a 2-3 week period. A service company would ideally want to acquire as much data with as many clients as possible during that time period, and technical, logistical or weather issues could hinder the number of clients they could service and the quality of the data obtained. Additionally because of the small time window, and the high costs of drone technology and expertise, service companies would need to ensure as many clients are met with during this 2-3 week period as possible in order to remain profitable while maintaining competitive and attractive pricing. While pricing would likely vary for type of drone being used, expertise employed, crop, and field size, this study's interviews showed that the orchard owners would likely pay $100-$500 for each set of data acquired on the 16 acre farm. Although the price would likely be higher on large scale farms, service companies and drone manufactures will have to convince farmers and justify the value of the product/service that only just gives them data regarding their crop, as compared to other farming equipment such as a $40,000 tractor which can yield tangible results. In this study the drone used was priced at around $20,000, with the added thermal sensor priced at an additional $15,000. In addition, to properly use and analyze the data acquired from the UAS, program licenses and personnel training which will cost additional time and money. This would make it difficult for a UAS manufacture to sell its product to an independent farmer, even if it's a large scale farm, as the farmer will likely compare cost benefit analysis the UAS to equipment they are already using such as a tractor, which is something which they would know can yield tangible results. While the UAS can gather and display farm data easily to the farmer, this is all data they can to a large extent glean on their own through traditional methods. While this information or at least the magnitude and clarity of data obtained via drone may be impractical for a famer to obtain with traditional methods on large scale farms, the idea that this piece of costly equipment and training will only yield something that they can theoretically do on their own almost as well, may be enough for the farmer to dismiss the product, and spend the money elsewhere.

Because of this, UAS manufactures may be more inclined to sell inexpensive, smaller/simpler UAS's with integrated or built in sensors to farmers and market them as a great way to easily gather data for problem areas. These manufactures may be more inclined to have FPV (First Person View) cameras on these drones with colour gradients and values such as NDVI or canopy temperature displayed on the HUD (Heads Up Display) of the UAS ground control station or even better, a smart phone app. This method would complement traditional farming practises, rather than being seen as a replacement or outsourcing of the practise. In some cases the farmer may only need the timely data that can be acquired from a short FPV drone flight that would to help tour his/her own field or in certain trouble spots. During the interviews with the orchard owner, they revealed that in some cases all they may need from the UAS is just an overview of the crop canopy temperature. Having this in real time can allow them to take this information and add it to their own traditional methods and to therefore make better informed decisions on where to irrigate the field or when to spray to prevent crop freezing during spring freezes. A full CWSI analysis may not be necessary, or at least not needed as frequently during the growing season.

This could also be said for service companies as well with technicians simply operating the UAS and working with the farmer. Such methodology would require less training, and cheaper equipment. A thermal camera on a DJI Phantom drone could potentially achieve this and cost under $6000. This methodology may only be viable on smaller fields or operations since the sheer size of a larger field may require a full mosaic in order to get a comprehensive overview of the field as the farmer may not be as familiar in detail with the larger field. However, this method could be used in larger fields if the farmer is keen to look only at specific trouble spots or has a well-defined area of interest.

Drone manufactures and service providers will have to overcome these cost benefit challenges for their own services. As mentioned earlier, they will not only have to convince farmers to utilize this technology, but also educate the grower on its prospects and the cost-benefits it can provide to the grower. Recently Measure, a drone solutions company, has released a free farm drone calculator to help farmers determine if a drone service is worthwhile on their farm. This calculator includes inputs into crop costs per a bushel, irrigation and fertilization costs, and the estimated savings according to farm size. While this calculator only accounts for the value acquired from NDVI imagery, and even with just NDVI imagery is unable to calculate all potential costs and benefits nor the potential logistical difficulties discussed earlier, tools such as these not only educate farmers on the benefits of the technology but potential estimate costs in such an endeavor. This is something that was difficult for farmers to do without getting a direct quote from a drone service provider. Imagery obtained from other camera sensor or algorithms such as CWSI, a DEM of the field or other health attributes such as nitrogen stress could also have new unforeseen cost benefits to the farmer.

Based on the arguments made earlier in this section, the best option to make this technology accessible to all producers would depend on the both the size and scope of the farm, and also what information the grower is most interested in obtaining from the technology. Smaller farms can likely conduct their own flights with smaller drones as they will likely have in-depth knowledge of their own field and be looking for something specific with the drone or to contextualise their knowledge. The scope of their field would allow the use of a smaller cheaper agriculture drone and can be done in a timely manner. While they will likely won`t have the education for complex analysis or be able to devote the time to learn them, a simple NDVI analysis can still reveal trouble areas as it is still used as an overall indicator of plant health and the processing needed to view the data in a orthomosaic if needed can easily be done on most home computers. The small size and familiarity of the field could easily allow the farmer to identify the cause of and solution to any issue found in a simple NDVI scan. However for more complex operations such as finding values other than CWSI or for much larger fields, a UAS service provider from a company would be recommended. The scope and size of a larger field would make it difficult for a famer to conduct the flights and analysis themselves as they would likely need more batteries and specialized equipment, and even larger time devoted for both operation and the needed education. A service provider would likely have the skills, expertise, and time to conduct such operations on the scope or specialized mission detailed by the farmer.

Both scenarios however would still require a degree of education for the farmer. Smaller famers would need to learn what the NDVI shows, how to operate the UAS and the regulations outlined by Transport Canada. Larger farmers or smaller farmers looking for specialized missions, would need be educated on what camera sensors on UAS`s are capable of providing for them and examples on how they can best utilize this information. This can best achieved via workshops provided by the UAS hosted by the UAS service providers. UAS service providers would want their client base to understand what the UAS can bring to their field and if they even need their service, as an operation on a smaller farm may not even be profitable. These same workshops can build and maintain a client base with both large and small farmers. The service provider can also act as a distributer of smaller agriculture UASs and offer maintenance services, separate education workshops on simple operations and regulations. Thus they can still maintain client base with smaller farms for more complex operations and maintain a profit through sales and workshop services. While the service providers are providing a service in information on how to optimize the farmers production, and it is in their best interest to provide honest information to build a recurring service with the client, farmers have a history of being wary of other service providers as they feel they can over exaggerate the benefits of their service/product in order to push sales. Thus in order to educate farmers on the benefits and uses of UAS's, it may be best if it comes from a third party source such as the government or a not for profit organization. This can be difficult to implement for a government or NGO due to the need of specialized personal, changing landscape of the technology and regulations and the associated costs.

7.4 Barriers to Overcome

The major technological barrier to overcome would be the image quality acquired via thermal cameras. Current thermal cameras and most thermal camera research are focused on crops that occupy the entire field, such as corn wheat and soybean, where there is lower risk of encountering mixed pixel issues. Trees in apple orchards are spaced out and the low resolution of the camera can create mixed pixels with both the soil beneath them and the grass/soil between them. While flying lower can be a simple fix to this resolution issue, many commercial apple orchards are large acreage fields where a lower flying UAS would require more extensive mission planning, time management, battery management and image processing/analysis. There are other many general technical barriers that would need to be overcome to make this technology more accessible to farmers. These include: longer lasting batteries to cover the large fields, more durable UAS frames and components to resist crashes, improved flight controls and signal strength to better control the UAS on windy days, as well as weather proofing to ensure better flight in wet conditions. These however are improvements that are currently being researched in every application of UAS use and will likely come in time.

Regulations will be another barrier to overcome for future growers who wish to utilize the UAS technology. Part of this is due to the technology still being very new and that government regulations are still catching up to the technology. Currently the regulations that are needed to be adhered to for UAS operations can be found online, but the details for the requirements for commercial operations and SFOC are more difficult to locate and interpret. This can be particularly difficult for farmers who are applying for a SFOC the first time as they may be unware of the long periods of time it may take for an approval. A recommendation to help ease the time and to educate new users of commercial UAS's would be to provide an easily accessible step by step guide on applying for an SFOC and provide examples of a good quality SFOC. These should also include a variety of examples from different industries and applications with the drones, including the agriculture industry. Education on agriculture UAS should also be available from government sources that are more frequently visited by farmers and growers, such as OMFRA (Ontario Ministry of Farms and Rural Affairs). They could even provide a separate space on agriculture UAS's providing the need to know information and guides. Additional creation of a news outlet and optional account creation from government sources can help build a community of UAS agriculture users.

7.5 Additional research that needs to be done

There are many opportunities and needs for further research. As mentioned by the growers in this study, apple scab and fire blight are major threats to the orchard. Currently, there are successful methodologies in detecting both fire blight and apple scab using camera sensors such as those employed by Delalieux et al (2009), Alnaasan et al (2015). However, both of these methodologies have only been employed in labs and greenhouses. Further research would be needed to employ these methods in a practical outdoor setting where there are many more variables to account for. In addition, a methodology would need to be developed to effectually use the camera sensor across the entire orchard. While using a UAS could be a potential method, these studies all used high resolution hyperspectral sensors, which are often too large or heavy to be currently mounted on all but the largest of drones. It may be possible to employ such methodologies to smaller multispectral camera sensor on a drone, but it is unknown if such methodologies would work with the camera facing down at a higher altitude above the target crop. The growers also mentioned that an apple counting methodology via a camera sensor would also be useful. Wang et al (2012) has already shown practical methods of apple counting using a camera sensor setting in an outdoor orchard. A future research project could apply this same methodology using inexpensive commercially available low flying quad copters or a ground based drone. Freezing was also a large issue for the growers this past season. A future research study can explore the use of a thermal camera on a quadcopter UAS with FPV for viewing crop canopy temperatures to determine if and when crops needed to be sprayed to prevent freezing.

While calculating CWSI may not be a top priority for UAS farmers currently, it is likely to become more important with the predicted effects of climate change. There are also several opportunities for future studies to improve the CWSI calculation methodologies used in this study. The UAS for this study was already amongst the best available commercially, particularly the thermal camera. As such, it may be more practical to use a lower flying quad copter to fly specifically over rows of saplings to acquire CWSI in a future study. This study would also need to ensure that the images were captured during optimal environmental conditions. A potential alternative to CWSI calculations could be to focus on the camera sensing techniques that identify soil moisture concentration such as those employed by Paltineanu et al (2013) and Soliman et al (2013) when acquiring data on crop water stress for apple saplings. Further studies would need to apply these techniques in the context of apple saplings in the orchard and with the camera sensors mounted on a UAS. The potential advantage that these techniques would be that the UAS could still fly high enough to capture the entire field in a timely method, while the resolution of the image could be used to identify soil moisture beneath the saplings rather than flying low enough to capture the thin saplings in the imagery. The CWSI model created in this study could theoretically be used to calculate the CWSI of any plant if it were to receive the correct slope and intercept values of the VPD chart for the target plant and region. While these data may not give empirical values, they may still give CWSI values that are relative to the entire study area. However, this would need to be confirmed in further studies using VPD values that are already known to be accurate for the plant in the region.

Conclusion

This study explored the practicality and feasibility of using UAS for apple orchards in Southern Ontario. After interviewing local apple growers with CWSI, NDVI and DEM data sets, this study demonstrated that there is indeed potential usefulness and benefits for the farmer in obtaining this data, particularly if it is colected at appropriate times during the growing season, NDVI and CWSI can provide valuable information on the overall health and progress of their crop. These include information such as: identifying problem areas, help them contextualise the knowledge of their field, and provide the necessary information and data to make any changes, interventions or applications to the field. It seems that while there are specialized health attributes information on the crops such as CWSI, farmers are more likely to take this information at face value and compare to other general readings such as NDVI. This would be used to identify problem areas that require ground inspections as the poor readings from these values are likely the result of something more complex occurring in this area, and likely need more attention. Thus UAS applications for at least smaller farms would work best if they are used as another tool or extension of traditional methods rather than in supplanting them.

Current UAS applications have impressed farmers and they do believe that UAS's can provide them with important added information. Growers interviewed believed that UAS's can be most helpful to their farms by being able to provide early detection of diseases such as apple scab and fire blight, crop temperature canopy detection to prevent winter freeze, and crop yield predictions. While current research does exist for detecting these issues via camera sensors, further research is needed to operationalize and optimize this research in a practical non-lab setting and on a UAS mount.

While CWSI may not be an important health attribute for apple farmers right now, it is likely to become more important as climate change will likely bring less rainfall and longer periods of drought. CWSI analysis via a UAS may be seen as a possible water management strategy for fields and a possible measure for technological adaptation to climate change. However, further research is needed to refine the CWSI methodologies for apple production. The layout of the apple tree rows will require higher definition thermal cameras, or lower flying preferably quadcopter UAS to capture the crop canopy temperature without issues of mixed pixels. These same flights and research projects will need to ensure the data is acquired under optimal conditions, and may need to create a vapour pressure deficit graph for apples in southern Ontario. Despite the difficulties encountered during this study when acquiring the CWSI, the results still show values that are relative within the orchard. The methodology and framework of the CWSI model created in this study may also be applied to any plant with the right inputs, however this would also require further research to confirm.

Logistical, technical and weather challenges, many of which were encountered during this study, will need to be overcome by farmers or service companies when using this technology. Much of the data provided by UAS farmers are most advantageous when provided at specific times of the year. In this study, NDVI and CWSI data was most appropriate during the early weeks of July. This is a small time window in which to obtain this data when planning around weather, bureaucratic regulations, and personnel logistics. Weather especially is a potentially significant problem as it can only be planned for in the short term. Personnel logistics can also play a major factor for service companies as they would need to find enough time for transportation to multiple farms, cover costs, yet remain an attractive price. Unless farmers have access to a backup UAS, any technical failure before or during these weeks can result in a loss in acquiring the data needed for that growing season. While it may be easier for smaller farms to utilize small agriculture UAS's in their practise to complement their own traditional observation methods, larger commercial farms and any missions looking for complex or specific details will likely need a specialized service. These services will need to have the training of and knowledge of UAS flight, data analysis, UAS regulation in Canada and to assist in data interpretation for the farmer client. Regardless if the farmer hires a UAS service or conducts their own UAS operations, they will need a degree of education on UAS knowledge and interpretation. This would ideally be given by a third party who has no stake in UAS sales or services, such as a government or NGO program, however it may be more practical to be given as part of the services offered by the UAS service company to establish clientele trust.

It is important to note that this study is one of the first of its kind in academia and had numerous unknowns, particularly in creating an accurate CWSI from a UAS. While it was not able to create a method to obtain empirical accurate values for CWSI, the nature of using a UAS over an apple orchard which has uneven terrain and numerous points of potential error may never obtain a 100% accuracy. However, this study did show that the accuracy of CWSI values obtained are still consistent in relative terms within the orchard, and more importantly, established the level of usability and utility of such data to farming businesses. It also provides useful information for those considering how best to offer and deliver UAS services to apple farmers. This study has laid the ground work for future studies to use as a staging point to improve CWSI estimate accuracy, create new methods of observing health attributes or diseases in apple orchards, and obtain more information on the usefulness of UAS data for Ontario farmers.

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Appendix

Appendix A:

UAS Specifications

Hardware

Weight (inc. supplied camera)	Approx. 0.69 kg (1.52 lbs)
Wingspan	96 cm (38 in)
Material	EPP foam, carbon structure & composite parts
Propulsion	Electric pusher propeller, 160 W brushless DC motor
Battery	11.1 V, 2150 mAh
Cameras	WX (18.2 MP), S110 RGB, thermoMAP
Carry case dimensions	55 x 45 x 25 cm (21.6 x 17.7 x 9.8 in)

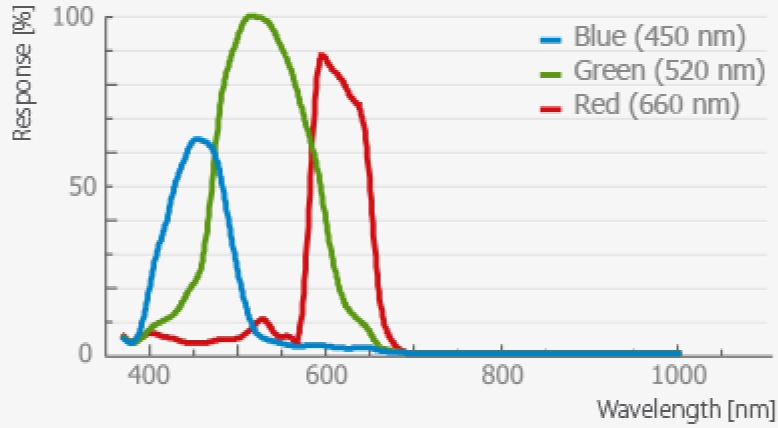
Operation

Maximum flight time	50 minutes
Nominal cruise speed	40-90 km/h (11-25 m/s or 25-56 mph)
Radio link range	Up to 3 km (1.86 miles)
Maximum coverage (single flight)	12 km2 / 4.6 mi2 (at 974 m / 3,195 ft altitude AGL)
Wind resistance	Up to 45 km/h (12m/s or 28 mph)
Ground Sampling Distance (GSD)	Down to 1.5 cm (0.6 in) per pixel
Relative orthomosaic/3D model accuracy	1-3x GSD
Absolute horizontal/vertical accuracy (w/GCPs)	Down to 3 cm (1.2 in) / 5 cm (2 in)
Absolute horizontal/vertical accuracy (no GCPs)	1-5 m (3.3-16.4 ft)
Multi-UAS operation	Yes (inc. mid-air collision avoidance)
Automatic 3D flight planning	Yes
Linear landing accuracy	Approx. 5 m (16.4 ft)

High resolution RGB images

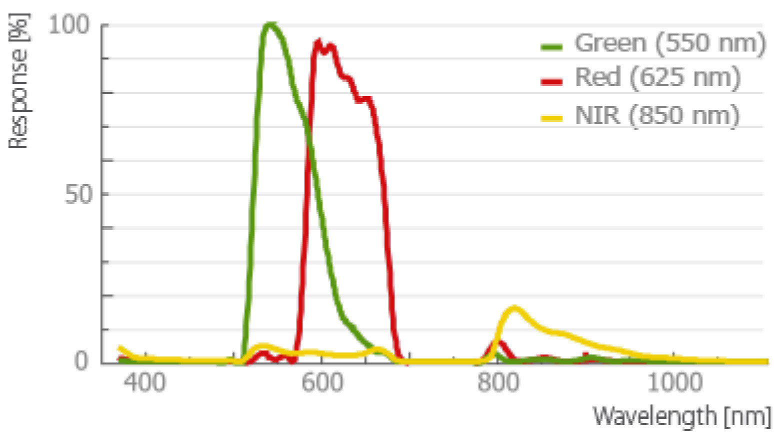
The S110 RGB provides standard Green, Red and Blue band data. This can complement data acquired by the cameras above with visual real colour renderings.

Band responses



Technical features

Resolution	12 MP
Ground resolution at 100 m	3.5 cm/px
Sensor size	7.44 x 5.58 mm
Pixel pitch	1.86 um
Image format	JPEG and/or RAW
Upward looking irradiance sensor	No



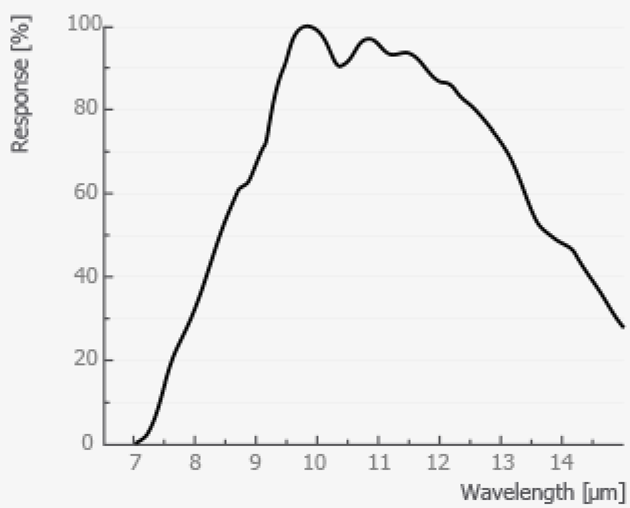
Technical features

Resolution	12 MP

Ground resolution at 100 m	3.5 cm/px
Sensor size	7.44 x 5.58 mm
Pixel pitch	1.86 um
Image format	JPEG and/or RAW

thermoMAP enables the eBee and eBee Ag to capture thermal video and still images, allowing you to create full thermal maps of a site (for example, to map water distribution, check irrigation systems or assess the functionality of solar panels).

Band responses



Technical features

Image size	640 x 512 pixels
Ground resolution at 75 m	14 cm/px
Scene temperature	-40 °C to 160 °C
Temperature resolution	0.1 °C
Temperature calibration	Automatic, in-flight
Output formats	TIFF images + MP4 video
Weight	Approx. 134 g
Operating altitude	75 - 150 m

Appendix B:

Interview Questions

About the orchard and owners

How large is the orchard?

What are the apples at your orchard used for? (pies, cider, juice, produce etc.)

How do you collect your apples?

What pieces of farm equipment do you believe are vital to maintaining and harvesting your orchard?

Do you have any concerns regarding the conditions and health of your trees? (ie water, diseases, pests, nutrition etc.)

Do you maintain a log or take notes on issues and areas of your orchard?

Do you irrigate your orchard?

What method of irrigation do you use?

On average how many apples do you harvest in a season?

What was it last season?

What were the weather conditions for last season like?

Did these conditions help or hinder apple production?

Did you receive any formal education regarding agriculture?

Do you have any form of tourism in your orchard? (I.e. apple picking)

Are you aware of the Ontario Apple Growers Association?

Are you a member of the Ontario Apple Growers Association?

Do you grow anything else besides apples or raise livestock?

What are values that affect how you make management decisions (e.g. money, Government, environmental concerns, etc.)?

What is most important to you about the management of your orchard?

When planning irrigation or watering your crops, do prefer to have specific values regarding how much water the crops needs, or do you just need to know how much water is needed relative to the other crops in your field? (I.e. the north side of your field which has traditionally been poorer than your south side now needs to be irrigated 20% more frequently than the south side to get similar uniform results across the field)

About UAS's and Agriculture

Do you use any technologies to actively monitor and measure attributes in your crops? (I.e. nutrient monitoring, crop yield prediction, irrigation mapping etc.)

Do you use any services to actively monitor and measure attributes in your crops? (I.e. nutrient monitoring, crop yield prediction, irrigation mapping etc.)

Before this project, were you aware that UAS's were being used in agriculture?

What about being used in apple orchards?

What information do you think UAS's are capable of showing to the grower?

What information do you want the UAS to show you about your orchard?

When would this information be most vital to you?

Do you have any concerns regarding UAS being used in agriculture?

Would you consider incorporating a UAS into orchard management practises?

If yes, what method would you employ the UAS on to your field?

- Purchase UAS and sensor equipment myself to fly on my own
- Hire a service to fly UAS and analyze my field
- Split costs with other orchard owner and jointly own the UAS
- Other

If no, what concerns would you want to be addressed before considering incorporating a UAS into your management practises?

During Charrete of the Orchard

Are you able to recognize your field from this map?

On this map could you identify trees or areas that have historically proven to yield less crop when compared to other trees in your orchard?

Can you identify the topography or your orchard from this map?

If you irrigate, can you identify any irrigation features or patterns on the map?

Are there any major age differences between trees on your field?

Are you able to identify these older or younger trees on the map?

Are there any other feature you feel is important on this map?

After Charrete of the Orchard

Do you see any similarities between the maps I have shown you and the one we drew on?

What were these similarities?

Do you see any differences between the maps I have shown you and the one we drew on?

What were these differences?

Are such pieces of information as CWSI, DEM, NDVI or their relationships useful to you as a grower?

When during the growing season would these pieces of information be useful to you?

What would make this information be more useful to you as a grower?

Appendix C:

Interview Questions

About the orchard and owners

How large is the orchard?

11 Acres

What are the apples at your orchard used for? (pies, cider, juice, produce etc)

Primary: Pick you own orchard (tourism), self made produce (tourism). Secondary: Light grocery

How do you collect your apples?

By hand with full time employees

What pieces of farm equipment do you believe are vital to maintaining and harvesting your orchard?

- Tractor, most important piece and most vital. Does all the heavy lifting and central equipment for various attachments including the flyer (chews up sticks) and sprayer . Costs around $ 40 000
- Other vital equipment include, the mower $8000, fertilizer $2000, and spreader $20 000

Do you have any concerns regarding the conditions and health of your trees? (ie water, diseases, pests, nutrition etc)

1. Apple scab (due to an appealing look, not a health concern, but won't sell)
2. Fire blight
3. Mites
4. Spring time frost, currently lost nearly %50 of crop to a frost this year. Have to spray when temp dips below -2°C

Do you maintain a log or take notes on issues and areas of your orchard?

Spray log book, and record areas of apple scab breakouts

Do you irrigate your orchard?

Yes, but only during the spring, on new crops/saplings and during droughts (no regular spraying). Drought is also only a issue on sapling (full grown have deep roots, thus not as affected by drought)

On average how many apples do you harvest in a season?

140-150 thousand pounds, last season replaced many old crops but this is a typical average

What was it last season?

140-150 thousand pounds

What were the weather conditions for last season like?

Cold and dry spring, effected many sapling. Sever cold winters kills many saplings as well and even some full grown trees to due trunks cracking.

Did these conditions help or hinder apple production?

Many freezing issues and needed constant spraying to keep warm.

Did you receive any formal education regarding agriculture?

Family trade, and some community college courses, but no formal degrees

Do you have any form of tourism in your orchard? (ie apple picking)

Yes, primary use

Are you a member or aware of the Ontario Apple Growers Association?

Yes a member, but not an active member as the association is geared more towards the commercial harvesting.

Do you grow anything else besides apples or raise livestock?

Christmas trees (extend the season)

Bee keeping (for pollination)

Small razz berry patch

Because farm focuses on tourism, we raise ducks and are considering a donkey to help maintain a "farm" atmosphere and feel. Our location is within the GTA with many customers from the Urban areas of Toronto.

What are values that affect how you make management decisions (e.g. money, government, environmental concerns, etc)?

Profit is the biggest value.

Environmental concerns are also a big concern. Actively help maintain surrounding forest and property as it helps maintain the farm image (for tourism) and have personal concerns as they are beside a large protected forest (happy valley forest). Also actively participate in grade 9 geography education tours in environmental and sustainable farming and eating, and general agriculture education.

About UAS's and Agriculture

Do you use any technologies to actively monitor and measure attributes in your crops? (ie nutrient monitoring, crop yield prediction, irrigation mapping etc)

No, traditional methods

Do you use any services to actively monitor and measure attributes in your crops? (ie nutrient monitoring, crop yield prediction, irrigation mapping etc)

Plant and soil analysis 1-2 a year with a consultant/ chemical company rep (often pushes their own products and feel they sometimes over exaggerate a threat)

Before this project, were you aware that UAS's were being used in agriculture?

No

What about being used in apple orchards?

No

What information do you think UAS's are capable of showing to the grower? (Before being shown maps)

Patches in rows and pockets

What information do you want the UAS to show you about your orchard?

Areas vulnerable to freezing and frost

Different temperatures of crop canopy

Soil moisture content

When would this information be most vital to you?

All

Do you have any concerns regarding UAS being used in agriculture?

No, but have some concerns over the costs of using UASs and value of the data.

Would you consider incorporating a UAS into orchard management practises?

Yes

If yes, what method would you employ the UAS on to your field?

- Purchase UAS and sensor equipment myself to fly on my own

- Hire a service to fly UAS and analyze my field
- Split costs with other orchard owner and jointly own the UAS
- Other

If no, what concerns would you want to be addressed before considering incorporating a UAS into your management practises?

During Charrete of the Orchard

Are you able to recognize your field from this map?

Yes, very easily

On this map could you identify trees or areas that have historically proven to yield less crop when compared to other trees in your orchard?

Can you identify the topography or your orchard from this map?

If you irrigate, can you identify any irrigation features or patterns on the map?

Are there any major age differences between trees on your field?

Are you able to identify these older or younger trees on the map?

Are there any other feature you feel is important on this map?

After Charrete of the Orchard

Do you see any similarities between the maps I have shown you and the one we drew on?

What were these similarities?

Do you see any differences between the maps I have shown you and the one we drew on?

What were these differences?

Are such pieces of information as CWSI, DEM, NDVI or their relationships useful to you as a grower?

When during the growing season would these pieces of information be useful to you?

What would make this information be more useful to you as a grower?