Using Agricultural Drones to Combat Rising Agricultural Input Costs and Improve Farm Efficiency

Lukas Schaeffler

For Above Sensing

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Rising Costs

Agricultural producers all over the country have been experiencing above-average input costs for their farming needs. Nitrogen-based fertilizer and fuel costs have been among some of the highest rising inputs for farmers from the years 2020-2022. According to the Canadian Farm Input Price Index, the following were the percentage increases from Q1 2020 to the most recently provided metrics of Q2 2022: machinery fuel costs increased by 108%, nitrogen-based fertilizer costs increased by 112%, and non-nitrogen fertilizers increased by 105% (Statistics Canada, 2022). While those statistics were some of the most drastic changes on the index it is important to note that every single category on the Canadian Farm Input Price Index has gone up since the first quarter of 2020.

The situation faced by Canadian farmers is the result of domestic and global occurrences. The beginnings of these increases can be traced back to the global lockdowns which began on January 23, 2020 (Koh, 2020). As China took drastic measures to contain the spread of Covid-19 within their country, the rest of the world soon followed and by, "*early April 2020, over a third of the global population was under some form of movement restriction or COVID-19 lockdown*" (Koh, 2020, pg.1). These initial lockdowns had catastrophic consequences on global trade and supply chains, driving up the costs of nearly everything that had to be shipped or transported. It is important to note that the price of fertilizer remained quite low in the months of May through July 2020 however, starting in August 2020, the price of fertilizer remained on a steady climb increasing 193% into September of 2022 (Fertilizers Price Index, 2022).

Covid-19 and the corresponding governmental lockdowns were detrimental to the flow of goods around the world, the agricultural industry suffered greatly under these conditions and food prices reflected this struggle clearly to millions of Canadians. As the global economies and world trading routes were beginning to stabilize, Russia invaded Ukraine on February 24, 2022 (Global Conflict Tracker, 2022). Russia's actions coupled with the responding sanctions of the Western states resulted in one of the largest increases in fertilizer prices ever seen (Jenkins, 2022). Fertilizer shipments were still able to go through to the rest of the world even under tight sanctions but, "*Russia's Ministry of Industry and Trade recommended that its fertilizer manufacturers temporarily stop exports of their products amid shipping concerns. Russia later announced further export restrictions on fertilizer that will last through May 2023 to secure sufficient supply for domestic farmers*" (Jenkins, 2022, p.2).

Russia halting its fertilizer exports affected farmers all around the world including Canada. Even before Russia's outright halting of exports, "*the federal government implemented a 35 percent tariff on all Russian imports, including fertilizer*" (Grain Farmers of Ontario, 2022, p.2). This restriction came into effect without the prior consultation of the agricultural sector, and the fact that Eastern Canada imports nearly 90% of all its nitrogen-based fertilizer from Russia, would make this a financially disastrous occurrence for Canadian farmers.

Canada has been decreasing its complete fertilizer imports from Russia from 2018 to 2020. This would have been a positive sign signifying a shift of dependency from Russian exports if Canada had not made their largest fertilizer purchase in 2021. Their 2021 purchase totaled $365 000 000 towering over the 2020 purchase of just under $150 000 000 (Trading Economics,

2022). With fertilizer being the main import from Canada from Russia it is fair to assume that losing this connection would be disastrous for the Canadian Agricultural Industry (Trading Economics, 2022). While the numbers are not out yet, there is a high probability that imports from Russia will be significantly less in 2022 than in 2021. With the 35% tariff on Russian fertilizer imports implemented by the Government of Canada and Russia all out halting exports, Canadian farmers are faced with record-high fertilizer prices which will affect their operational decisions on whether to continue farming or surrender the practice outright.

The final and perhaps most influential reason why fertilizer prices will continue to climb can be found in the Government of Canada's climate plan titled, *A Healthy Environment and a Healthy Economy.* One of the many stated objectives of this policy is to, "*build back from the pandemic in a way that meets the need to address climate change and to deliver a stronger economy that thrives in a low-carbon world to the benefit of all Canadians"* (Environment and Climate Change Canada, 2020, pg5). This plan is segmented into 5 categories which all attempt to promote climate stewardship in Canada and help bolster the Canadian Economy to return to pre-pandemic levels.

The Category titled, *Building Canada's Clean Industrial Advantage,* in the subsection, *Climate Smart Agriculture,* the document aims at, *"the adoption of cleaner practices and technologies that further reduce emissions and protect the land, water and air that farmers depend on for their long-term sustainability"* (Environment and Climate Change Canada, 2020, pg. 45). According to Environment Canada, an approach to achieving this goal consists of reducing agricultural fertilizer usage by, "*30% below 2020 levels"* (Environment and Climate Change Canada, 2020, pg. 45). With Canada's reported usage of 132 kg of fertilizer per hectare of arable land in 2020, adhering to this policy would reduce that number to 92.6 kg of fertilizer per hectare of arable land (Trading Economics, 2022). If this plan were to be enacted into law, it would greatly limit the amount of available fertilizer to farmers hence driving up its price, as well as decreasing potential crop yields due to the fertilization limitation.

This paper focuses mainly on the increases in fertilizer prices as it is arguably one of the most important agricultural inputs, however, as previously mentioned every single input on the Canadian Farm Input Price Index has gone up since the beginning of 2020 (Statistics Canada, 2022). The reality is that input prices will continue to climb due to shortages, governmental efforts to defer consumers from fossil fuels such as carbon taxes, and the overall inflationary state of the economy. If they are to remain in business, farmers must begin to prioritize their input management practices saving where they can, minimizing waste, and increasing efficiency. One avenue of achieving this goal could be through the mass adoption of precision agriculture.

Precision Agriculture

"*Precision agriculture is a method of farming that uses technological innovations – including GPS guidance, drones, sensors, soil sampling and precision machinery – in order to grow crops more efficiently*" (CropLife Canada Staff, 2019, p.1). It is the application of conventional and developing technologies to quantify aspects of farming to make it as productive and efficient as possible. This method of approaching land management can have positive impacts on a farming operation if the farmer desires to increase efficiency and productivity while decreasing input costs. "*In crops, precision agriculture is seen in the closely managed use of inputs such as fertilizer and pesticides. It's guided by site-specific data gathered through advanced technology such as aerial drones and satellite mapping. Such data help farmers determine the exact placement and amount of inputs required, reducing waste and exposure and lessening their environmental impact*" (University of Guelph 2016, pg.1).

Drones in Precision Agriculture

Agricultural drones fall under the umbrella of precision agriculture and their applications are vast. They can be used for data collection, "*crop mapping, field analysis, spraying and crop monitoring*" (Times Agriculture, 2022, p.5). Regarding agricultural applications, there are two drone types which are commonly used: fixed-wing and rotary-wing (Times Agriculture, 2022). Fixed-wing platforms are advantageous in that they have longer flight times and consume less power than rotary platforms. The capability of being able to spend prolonged periods in the air makes fixed-wing drones the primary choice for data collection operations (Times Agriculture, 2022). While rotary platforms have shorter flight times than fixed wings drones, their advantage is in the fact that they can hover and have superior maneuverability (Times Agriculture, 2022). Due to their advantages, agricultural rotary drones are primarily used for, "*pesticide spraying and crop mapping*" (Times Agriculture, 2022, p.4).

The remainder of this paper will primarily focus on the fixed-wing platform and how the data collected by such drones can assist farmers in informed decision-making to help reduce input costs. The use of drones in precision agriculture allows for the collection of multispectral imagery which can provide agriculturalists with valuable and actionable data.

Multispectral imagery is images that are collected using specialized cameras with lenses capturing a specific range of light. Multispectral imagery is used as the basis on which various plant health assessments are carried out. One main and proven methodology used for plant health assessments uses the spectral reflectance of plants, which can provide insights into plant type, the water content in tissues, and other physical properties of the plant (Chang et al. 2016, Xue et al. 2017). The main way to quantitively measure various physical properties of plants is through the creation of vegetation indices (VI).

VIs are calculated by combining various different spectral bands through mathematical equations depending on different applications. There are a variety of spectral indices, but the ones that have been mostly used and studied for agriculture include the Normalized Difference Vegetation Index (NDVI), Crop Water Stress Index (CWSI), and Normalized Difference Red Edge Index

(NDRE) (Xue et al. 2017). These indices can provide an agriculturalist with data-driven information regarding the state of his or her plants in the context of nutrient levels, water concentration, and disease.

Drone Application vs Traditional Methods

In comparison to traditional methods of agricultural data collection, drones have been showing themselves to be superior concerning accuracy, timeliness, and repeatability. Data collection in this aspect refers to all capabilities that can be performed with a drone platform and the accompanying payloads. While the uses of these machines are vast, this comparison will examine how applying drones to critical farming tasks such as crop scouting/disease identification, irrigation management, and input control compares to traditional methods.

Crop Scouting and Disease Identification

Historically, crop scouting, which is the process of observing one's field, documenting growth patterns, and detecting any issues/diseases that might negatively affect harvest season, has been done by scouts either walking the field or using an all-terrain vehicle (ATV) to drive and inspect crops at various locations (Agriculture, Technology, and Business Market, 2019). Using the traditional method, crop scouts can get within arm's reach of the plants and examine them thoroughly. While this method has been effective to historical standards and has been used for many years, it has significant drawbacks.

If a producer would want to gather data on all the crops in his or her operation it would be a time-consuming task for the scouts to visually inspect and assess every single plant. In British Columbia alone, 28, 072 ha is dedicated solely to fruits, berries, and nuts it would be a costly and time-consuming undertaking to inspect every square inch of those fields and detect any issues promptly (British Columbia, 2021, pg1). While methods are in place to inspect certain plots of land and guestimate the state of the remaining product through statistical extrapolation, they do not produce an accurate assessment of the plants on the plot. It is very difficult to account for all variables present in a dynamic environment such as a field exposed to diverse natural elements. If such potentially faulty information is acted upon, consequences could be dire resulting in decreased agricultural yields, suboptimal harvest, and undetected issues such as disease.

The Drone Approach

Crop scouting with drones can help reduce the risk of acting on faulty information. Rather than extrapolating a sample taken on a field, a drone can map the entire operation and provide data on a per-plant basis. Furthermore, depending on the payload, a fixed-wing drone such as the WingtraOne can cover up to 400 ha in a single flight lasting 52 minutes (Wingtra Knowledge Base, 2022). In comparison to a crop scout who, "*in fields of 80 to 160 acres, checks at least five to seven locations. For larger fields, observe at least 10 to 15 sample locations*

(McKenzie, 2017, p.5)*"* The machine can gather more data, in less time, and with more accuracy. The data can then be processed and sequenced to provide precise information about the state of the plants. With advances in AI and machine learning the data can be processed to identify and pinpoint known or novel diseases giving the farmer valuable information that can be acted upon to prevent any severe developments that might impact yields, plant health, and ultimately the success of the harvest (Mohanty et all.,2016) It is important to note that even if the drone technology cannot identify the specific disease, it can most definitely locate the exact problem area and scouts can be dispatched to investigate further, this saves the scouts time as they are not looking in the blind and are acting upon exact and up to date information.

Compared to scouts, drones can gather data for farmers frequently to provide the producer with the best available and most up-to-date data. Flights can be scheduled at the farmer's request on a daily or weekly basis, the data can be provided and processed within 24 hours of the flight. This option provides the farmer with consistent and up-to-date information about his or her farm that can be used to identify problems, increase efficiency, and lower input costs. With the increase of unpredictable and extreme weather events due to climate change, it is paramount that farmers utilize frequent flyovers if they intend on reducing their inputs. Smart management as outlined above is a sure way to stay on top of one's operation and remain informed about every square inch of the crop.

Irrigation Control and Water Allocation

Agricultural irrigation is responsible for the consumption of, "*70% of water use worldwide"* (OECD, 2017, p.6). Water is not the most expensive farming input; however, it is critical for the health and growth of crops. "*Canadian agricultural producers used approximately 1.8 billion cubic metres of water to irrigate their crops in 2020"* (Statistics Canada, 2020, p.1). The amount of water that is used is dependent on the crop type, topography, and the amount of rain present during the growing season. The following are breakdowns of total Canadian water use (1.9 billion Cubic Meters) by crop type in 2020: "*Field (50%) and forage (37%) crops used the most irrigation water across the country, with fruit (8%) and vegetable (5%) crops accounting for the rest"* (Statistics Canada, 2020, p.1). "*Water is supplied to a farm in one of four ways: water from on-farm underground sources (e.g., wells), on-farm surface water sources (such as lakes and rivers), off-farm sources, and other water sources"* (Statistics Canada, 2020, p.3).

The majority of agricultural water is sourced from provincial sources, "*as reported in Alberta (97%), Saskatchewan (94%), and British Columbia (69%)* (Statistics Canada, 2020, p.3). Any water stemming from provincial sources is controlled by "*irrigation districts and projects"* which require payment (Statistics Canada, 2020, p.3). In most instances, farmers attain specialized water allotments; however, it is an expense that has the potential to increase as droughts and extreme weather events are on the rise increasing the scarcity of a stable water supply (Wheaton et al., 2018) Another factor that farmers must consider is that with rising temperatures associated with climate change growing seasons will be longer. More water will be required due to the longer seasons and as a response to the higher temperatures, farmers will

need to irrigate more to keep their crops at optimal moisture while combating the hot weather (Wozniki et al.,2015).

Currently, there are a few effective methods in place that can help reduce water waste. Those specific to water allocation practices include using a "*soil moisture monitoring device or climate information to determine when to irrigate and refraining from irrigating during hot windy periods of the day if possible* (Ministry of Agriculture, 2015, pg.1/2). Other practices include visually inspecting where water is landing and walking the field to make sure that it is receiving moisture. While the visual verification method may work well with overhead irrigation systems, it will become more difficult to assess the effectiveness of one's allocation visually with ground-level emission irrigation systems. In a large cherry or grape farm, it would be nearly impossible to visually inspect all irrigation emitters regularly and accurately. Even if one sparkler or emitter is faulty, it can have consequential effects on the health of the plant it is watering increasing the chances of diseases and negative heat effects. Finally, while it is rather easy to detect if one is experiencing a leak in a farming operation due to meter readings, and decreased pressure, it can be difficult to locate the exact location of the leak leading to a lengthy process of wasting water.

The Drone Approach

Managing irrigation water allocation with drones has many advantages compared to the beforementioned methods (Krapez et al., 2022). The drone has an advantage in the speed at which the data is collected, its accuracy, and the ability to repeat the task as seen appropriate by the client. During a flyover, a drone operator can utilize their payloads to display thermal imagery to detect water spread. If a farmer requested data about his or her water allocation, a flyover would be conducted directly after a watering period to gather the most up-to-date data. Through this data, a producer can attain information as to how effectively his or her sprinklers are distributing water, if the water is being distributed uniformly if certain areas are at risk of drying out, and whether there are damaged or functionless sprinkler heads in his or her field, all this data is possible to be received within 24 Hours. This information can lead to direct and informed action that can be taken by the farmer to optimize his or her water allocation and ultimately reduce waste leading to lower inputs used and lower costs. Finally, if a farmer were to adopt such drone technology into his or her regular water management best practices, he or she can keep monitoring their fields on a daily or weekly basis to perfect their operation and to make decisions based on the most accurate and most importantly most recent data.

Leak Detection

One of the greatest sources of agricultural water waste are undetected leaks (Marsh, 2020). Not only do they cost the producer due to increased water payments (assuming he or she is not using well water), but they also make delivering water to crops more difficult and straining, not only to his or her operation but also to the pump houses and distribution networks of the district. The rising temperatures associated with climate change will challenge farmers on

multiple fronts, with water management being one of the most critical areas. Firstly, as temperatures rise growing seasons are becoming prolonged (EPA, 2020). While this may allow the farmer to increase his or her yields, it also means that there will be heightened demand for water usage to maintain the crops. Secondly, with temperatures rising, plants require more water to preserve their moisture due to increased evaporation (Cho, 2022). Finally, as droughts and extreme weather events are becoming commonplace, water for irrigation is becoming less available, as scarcity increases, the price of the resource tends to follow, and seeing as the farming inputs are on the rise, having effective methods to control water waste is a critical step to save operational costs as well as the resource itself.

It is simple to detect whether one's operation is experiencing leakage; this is done by halting the function of one's irrigation system and monitoring the readings of the water meter. If a leak is present on the downstream side of the meter, the water meter will continue turning over signifying a leak. Further investigation can be done manually by exercising individual valves in an effort narrow down where the break could be and what is causing it. The downside to this method is that it is time-consuming and cannot pinpoint the exact location of leaks, as they are not limited to faulty valves and can also occur in broken lines downstream or upstream from them. Other ways of detecting leaks include visually looking for water that surfaces or utilizing advanced ultrasonic technologies.

Ground line leaks can be incredibly inconvenient and expensive for farmers, especially if they require excavation to be repaired. Producers may see where the water is surfacing and instruct crews to dig in that general direction, however, often the leak is not located directly where the water surfaced. This leads to a long and drawn-out process of chasing the leak while excavating soil, costing the farmer every minute of the excavation. There is also a possibility that a farmer might use his or her equipment to repair the leak which may lead to decreased productivity due to the preoccupation of the equipment on digging and not tending to daily farming needs.

While leaks are not initially as destructive to farms as droughts, fires, or other severe occurrences, they act can act as long-term strains to agricultural producers and their stakeholders if left undetected and unrepaired. Depending on the severity of the break, water will either not reach its intended crops or reach it in decreased amounts and at the expense of the health of the plants, yields, and the profits of the farmer. A prolonged leak will also put a strain on the very infrastructure responsible for its transport. A break in a water line will significantly decrease the amount of pressure found within it, if a farmer keeps irrigating through that channel, more volume will be required forcing pumphouses to work extra to keep up with the increased demand. Other than the severe water waste, this strain will also affect the amount of water available to other farmers in the area. Ultimately, while often undetected or in some cases ignored, leaks can have catastrophic consequences and cause ripple effects that negatively impact a multitude of stakeholders.

The Drone Approach

The adoption of drones in the management of farms can help the farmers reduce and, in some cases, eliminate the above-mentioned issues. Agricultural drones can be outfitted with sensors which can detect thermal signatures. Water will register as a different colour/heat once the data is processed, and areas of concern can be isolated and localized. This process is known as leak scouting and can be done at the request of a farmer who cannot locate an exact leak location or suspects that a leak may be present on his or her property. However, agricultural drones can collect and process more than one data set at a time. This means that leaks or water signatures that are out of the norm can be detected during routine flyovers and farmers can be notified of the issue even before they realize that it is happening.

Thermal data collected by drones also has the advantage of easing the repair process. As before mentioned, water will sometimes surface close to the location of a buried and broken water line. However, this does not always mean that the tear is directly underneath the area of surfacing. As water takes the path of least resistance it can travel beneath the ground for substantial distances before finding its way to the surface via a less resistant path. Through analyzing the thermal data, inferences can be drawn as to where the exact location of the break could be, this is done by measuring the intensity of the thermal signature and finding the coolest point of the map, this will most likely be the location of the line break as it would contain the most intense water concentration of any other area of the map. After finding the most likely location for the break itself crews can be directed to act on the repair based on the best available information.

Fertilizer Application

Fertilizer is one of the most important inputs for crop-growing farmers across the board. Its main use is to supply plants with additional nutrients leading to healthier and larger crops. This results in agricultural producers being able to attain high yields enabling them to keep their employees paid and maintain a productive operation. Fertilizer use is integral to the productivity of virtually every crop-growing operation and its use has been on the increase while the overall landmass of farmland has been on a steady decline (Dorff and Beaulieu, 2011). This is because, "*as crops grow, they deplete the soil's fertility by absorbing nutrients from the land*" fertilizer is used as a way to bring depleted nutrients back into the soil to ensure an ideal growing environment and fruitful harvest (Dorff and Beaulieu, 2011, p.1). However, this trend of increased fertilizer use and the decreasing number of farms has a significant financial impact on farmers as well as drastic environmental implications.

As previously mentioned, fertilizer prices have seen historic rises since the onset of the Covid-19 pandemic in 2020 (Statistics Canada, 2022). It is one of the fastest-growing expenses on the Canadian Farm Input Index and remains historically high due to current global occurrences as well as the influence of domestic environmental attitudes and policies outlined at the beginning of this paper. Fertilizer is vital to farmers who intend to produce enough output to remain profitable or at the bare minimum to maintain their operations. However, as time continues, producers will require more fertilizer to maintain their current yields. Not only does this have severe financial implications, since an already expensive and critical agricultural input

is required in higher quantities, but this gradual increase in the application also has significant environmental impacts as well.

Before the second world war, applying chemical-based fertilizers was unheard of and costly, however, in the late '40s munitions factories were transformed to mass produce it (Gerhert et al, 2015). This transformation was possible as the factories required large amounts of ammonia and nitrogen to produce armaments, the two chemicals are also critical components in chemical fertilizers, this allowed for the mass production of fertilizer consequently driving down its price and making it more accessible to farmers around the globe (Gerhert et al, 2015). Growers quickly came to realize the advantages that fertilizer provided them, and it quickly became adopted as a farming standard around the globe.

As more fertilizer was being applied, farmers were able to benefit from the increase in production however, this benefit did not come without consequences. Over time, the frequent harvesting of crops depletes the natural nitrogen levels in the farm's soil. As discussed before, fertilizer acts as a supplement to this lack of nutritious topsoil. Over time the fertility of naturally occurring topsoil has been on the decline, driving up the demand for artificially boosting soil health with chemicals.

With the increased use of fertilizer over time came grave environmental consequences as, "*nitrogen fertilization represents one of the main agricultural practices with a high emission of pollutants into the atmosphere, soil, and water*" (Luqueno et al, 2014, pg.3). As high amounts of the chemical are applied and are not completely absorbed by crops, the excess fertilizer can run off into neighbouring areas, waterways, ecosystems, and even "l*each through the soil and into groundwater over time*" (EPA, 2022, p4). This can have the potential to cause severe environmental harm as, "*High levels of nitrogen and phosphorus can cause eutrophication of water bodies*" (EPA, 2022, p.4). Eutrophication causes, "hypoxia *("dead zones"), causing fish kills and a decrease in aquatic life*" (EPA, 2022, p.4). The consequential over-application of nutrients into water systems can also lead to," *harmful algal blooms (HABs) in freshwater systems, which not only disrupt wildlife but can also produce toxins harmful to humans*" (EPA, 2022, p.4).

The severe consequences that fertilizer can pose to ecosystems, animals, and humans are causing governments to act. As discussed in the opening of this paper, A Healthy Environment and a Healthy Economy is the Canadian Federal Government's policy guide related to combatting pollution and climate change. This plan intends to reduce the issue of runoff by attempting to reduce Canadian fertilizer use by "*30% below 2020 levels*" (Environment and Climate Change Canada, 2020, pg. 45). While it may seem like a logical approach it is highly improbable.

Fertilizer use would at the very least need to remain at its current levels to maintain present yields. The goal of the government of Canada also does not consider that, "*the exponential growth of global population will lead to an increased food demand*" (Luqueno et al, 2014, pg.5). If alternative food technologies remain at their current unscalable levels, this increased demand will need to be met by growing more crops, hence using more fertilizer. The proposed objective is therefore highly unfeasible and if implemented, will result in drastic food shortages due to the substantially decreased crop outputs which will simply not keep up with demand. Not only will there be less food to nourish the population, but it will also greatly impact the pockets of farmers as their cashflows will be affected as well.

Fertilizer is not only expensive and potentially deadly if overapplied, but it is also greatly mishandled in the application process. "*Less than half of the fertilizer applied to the crop soil is actually recovered in crops*", considering that it is one of the most expensive and important inputs a farmer can have this revelation is concerning (Luqueno et al, 2014, pg.228). The main reasons for the 50% waste rate, "*occur through volatilization or leaching by rain, and this can lead to some important environmental problems. In addition, the parameters that affect the efficiency of fertilizer use are the nature of the soil, the climate, the technique of application of the fertilizer and the nature of the crops*" (Luqueno et al, 2014, pg.228).

The Drone Approach

Utilizing drones for monitoring the fertilization process can be extremely beneficial for ensuring the most effective and waste-free application of fertilizer. Agricultural drones will be able to help eliminate at least one of the above-mentioned causes of fertilizer waste. The technique of fertilizer application is one of the most consequential reasons for fertilizer misplacement and fortunately, it is the most manageable one.

Regular monitoring flights will be able to give farmers insights regarding the effectiveness of the fertilizer by displaying data regarding plant health via the Normalised Difference Vegetation Index (NDVI). As the growing season progresses, the data gathered via the flights will inform farmers which areas are healthy as well as which areas are lacking nutrients and require further attention and fertilizing. This approach will help streamline the re-fertilization process as areas only requiring fertilizer will be tended to eliminate over fertilization helping farmers cut down on input costs.

Furthermore, drone data collection and analysis can help agricultural producers ensure that they can provide detailed aerial data as supporting records for meeting different policy and best practices requirements. While preparing and implementing Nutrient Management Plans in the province of British Columbia, drones can support the collection of information needed for developing the Nutrient Management Plan, as well as help farmers ensure that their plants are using all the available nutrients as expected without having to do soil tests.

Nutrient Management Plans are currently required to be in place at farms who meet the following criteria; 1. *Their operation is 5 hectares (12 acres) or more 2.They have a livestock or poultry operation with 5 animal units* or more (includes all types of agricultural operations for the Hullcar aquifer) 3.Their post-harvest nitrate test is 100 kg/ha (89 lb/ac) or more 4.They are located in one of the following vulnerable aquifer recharge areas: Abbots ford, Grand Forks, Okanagan Falls, Sicamous, Chiliwack, Hullcar, Oliver, Spallumcheen, Cobble Hill, Langley, Ososyoos, Sunnybrae, Coldstream, Lumby, Penticton, and Tappen* (British Columbia, 2022, pg. 1).

Pesticide/Herbicide Application

Similar to fertilizer, the use of pesticides in agriculture has enabled farmers to harvest larger yields keeping up with the demands of a growing population. Mainstream North American adoption of pesticide use occurred towards the end of the 19th century, during this time, "*U.S. farmers were using copper acetoarsenite (Paris green), calcium arsenate, nicotine sulphate, and sulfur to control insect pests in field crops, but often results were unsatisfactory because of the primitive chemistry and application methods*" (Delaplane, 1996, pg.2). Post WW2 many advancements were made in pesticides improving their capabilities and effectiveness (Delaplane, 1996). The use of pesticides is standard practice for protecting crops from invasive species and diseases for the majority of farmers in the present day, as they enable agricultural producers to eliminate potential threats to their crops ensuring a higher likely hood of a successful and profitable harvest.

Benefits of Pesticides/Herbicides

Without the widespread adoption and use of pesticides, the world would have significantly less food. Pesticides are an integral part of modern agriculture and ensure that crops gain protection from the harmful effects of, "*weeds, insect infestation and diseases*" (EPA, 2022, pg.1). A more successful crop yield and improved crop quality are both interrelated effects of applying pesticides and have been a staple of agricultural practice globally (Cooper et al., 2020). There are also many secondary benefits that the use of pesticides brings forth such as increased financial security for farmers as their crops are more resilient to harm, the protection of human life as harmful diseases are eradicated from crops, and the general fortification of food security globally.

Risks of Pesticides

According to the Journal of Agricultural and Environmental Ethics, *Less than 0.1% of pesticides applied for pest control reach their target pests* (Pimentel, 1995, p.1). This leaves the remaining 99.9% of the pesticides to percolate into the ground or travel through runoff or wind negatively impacting surrounding ecosystems. While this study is dated, the reality of the inefficiency of pesticides reaching their targets has not changed hence it remains a frequently referenced source in even more recent sources such as the Journal of Environment, Development and Sustainability in 2012. ("*Pesticides, when used in high quantities, pollute soil and water, causing damage to its microflora and microfauna, and also hinder the absorption of important mineral nutrients by plants*" (Sharma et al., 2019, p.24).

Pesticide-related pollution has been a developing issue which is not only harming the health and function of critical ecosystems but also negatively affecting the effectiveness and profitability of farming operations. When most pesticides miss their targets due to ineffective application methods or natural causes, farmers don't only lose money on the product that was lost but they also incur more costs as they will most likely need to spray more to make up for the pesticides that lost their mark.

Current Application Methods

In current agriculture, the general pesticide application methods include the identification of the pest and selecting the proper pesticide and delivery device to apply it. The same applies process can be applied to herbicide application. While larger pests and visual crop diseases can be quickly identified via visual means and handled by conventional methods, large areas of farmland and less visual, developing, and unknown diseases may remain undetected until significant damage has been done to the crops, "Once the disease becomes visible on the leaf level, even spray may become useless" stated assistant professor Maitiniyazi Maimaitijiang, at the Department of Geography and Geospatial Sciences in the University of Dakota (Dehaven,2022,p.4).

There has been a global increase in plant diseases, both known and novel. (Ristaino et al.,2021). "Emerging plant diseases have already become more frequent, and in coming decades it is expected that shifts in the geographic distributions of pests and pathogens in response to climate change and increased global commerce will make them both more frequent and severe" (Ristaino et al.,2021, p.2). This developing reality has resulted in institutions such as the National Academy of Sciences releasing calls to action by publishing agricultural research agendas to find a solution for, "the need for breakthrough technology for the early and rapid detection and prevention of plant diseases" (Ristaino et al.,2021, p.2). Farmers are also reporting that one of the most challenging areas of managing their crop health is locating and identifying diseases before significant harm is done to the remainder of their crops.

The Drone Approach

The information collected by agricultural drones can assist farmers in detecting, identifying, and taking action against invasive species and diseases in their fields. Through the use of multispectral/thermal imagery, vegetation indices as explained in the precision agriculture section, and regular monitoring flights, agricultural drones can examine every square inch of a farming operation. Areas of concern can be identified once the data is processed, and through the application of machine learning, farmers will be provided with information about what specific diseases are present in their fields, how far they have spread, and their exact locations. The knowledge of the exact location alone will enable farmers to take informed action as to what they think is the best approach for handling the situation.

An area where agricultural drones show significant superiority compared to current disease/crop scouting methods is that through multispectral monitoring, they can detect diseases at their earliest stages before they become visibly detectable and spread significantly. This enables farmers to take quick and informed action, greatly reducing the possibility of more harm being done to the remainder of the crops. With such information, farmers can act accordingly. One such response could be to apply the appropriate pesticides/herbicides to the specific area of concern, halting the issue in its tracks as well as conserving the pesticide/herbicides used, minimizing risks associated with over-application, as well as significantly reducing their costs.

Through routine flyovers agricultural producers will be informed about the most up-to-date state of their crops, the effectiveness of their pesticide application program, as well as if any new diseases or pests are present in their grow. Drones will be able to provide detailed information regarding the effectiveness of pesticide delivery methods by utilizing thermal imagery to track coverage allowing farmers to adjust accordingly if there are any inefficiencies present. The effectiveness of the applied chemicals can also be measured via consequent data collection flights, which will assess the severity of the identified disease after the application of a herbicide or pesticide. If no progress is being seen, farmers can adjust by applying a different chemical or changing their approaches altogether.

Satellites Vs Drones

Satellite Applications

The use of satellites in agriculture has been an integral and developing component of the industry. They assist agriculturalists by providing Global Navigation Satellite System (GNSS) data as well as beneficial information regarding crop management, harvesting, and yield projections (Antognelli, 2020). There are options for farmers to access free, open-sourced satellite data which can help them make decisions about their farming approaches and priorities. While there are resources available for processing information provided by satellites, it is often quite general and can be difficult to decipher for people with no prior knowledge of the area.

The data provided by satellites has a low special resolution, meaning that a single pixel presented via satellite gathered information, will cover a 10 Meter area of the monitored field (SOWIT, 2022). 10 Meter pixel resolution is the standard however, other free services can have a pixel rating of as high as 60 Meters, while specialized and paid satellite services can present 1 Meter per pixel data in ideal conditions (Antognelli,2020). Due to the low special resolution of satellite imagery, the information gathered is most beneficial for large-scale and mono-crop agricultural undertakings which, "*means acquiring less details in favour of understanding the global heterogeneity of a farm or plot*" (SOWIT, 2022, p.4).

Farmers who rely on satellites for crop-related information must also adhere to the orbiting schedules of the machines. While it may vary on the type of satellite service which they use, agriculturalists can typically expect up-to-date information every 16 to 3 days (Antognelli, 2020). While this may be an acceptable time frame for some farmers it is not guaranteed that accurate or legible data to be delivered within those timeframes as factors such as visibility can be affected by cloud coverage rendering the sensors onboard the satellites severely obsolete. This reality can lead to farmers not being informed on the most recent state of their crops which has the potential to hinder effective decision-making regarding fertilizer application, irrigation, harvesting times, and pest/disease control strategies.

While some satellites are a free service that can benefit large-scale and mono-crop producers, drones outperform them on nearly every metric other than coverage. Drones have a significantly higher factor of spatial resolution, depending on the payloads that they are outfitted with, these machines can achieve a resolution of 3 to 0.7 centimetres per pixel (Wingtra, 2022). This implies that customers of drone services will be able to attain data regarding their entire farming operation and every plant to the most minute detail. Such an ability proves beneficial for farmers of all scales as current increases in costs require farmers to be informed about the well-being of their entire farm and to be able to act on information instantly and accurately if a potential disease or threat arises.

Drone services can be requested from the farmer to accommodate the needs of the client. If an agriculturalist requires immediate and detailed information about a concern regarding irrigation efficiency, potential diseases in his or her crop, or topographical data, he or she can request a flyover and have data provided to them as soon as it has been processed and analyzed. As drones fly closer to the ground, cloud coverage will have little to no impact on the drone's ability to collect data. The variety and accuracy of the information that drones can collect allow them to provide farmers with more actionable data than satellite capabilities could. As discussed in previous sections a UAV can assist in the process of detecting leaks, identifying diseases in their infancy, detecting invasive species, and topographical land/irrigation management.

Climate change and increasing input costs are challenging farmers requiring them to prioritize efficiency in their operations. While satellites are a valuable tool in precision agriculture and should be used where appropriate, they cannot compete with the amount of detail and insight that can be provided via a drone. Even in the coverage area where satellites have a clear advantage, fixed-wing UAV platforms have significant flight spans that can cover 400 + hectares in a single flight (Wingtra, 2022). The data gathered on such flights is more complete and more detailed than that of a satellite, further narrowing the gap in the coverage vs. quality of information.

Hesitancy to Adopt

The benefits of incorporating drones into agricultural management practices are clear and undeniable. Despite the savings in input costs, increases in efficiency, and overall improvements to farming operations that modern drone technology can bring agriculturalists, adoption rates have not reflected the purported benefits. A study conducted by the International Food and Agribusiness Management Association (IFAMA) provides a unique insight into farmers' adoption, attitudes, and grievances regarding drone technology.

Of the participants sampled in the study only, "*8% of the farmers in our sample were adopters and were currently using UAVs in their agricultural operations*" (Skevas et all., 2019, p.474). The study refers to the fact that this measurement was significantly higher among larger and more industrial farming operations compared to "smaller farms" which were upwards of 100 acres (Skevas et al., 2019). It is reasonable to assume that smaller agricultural producers may not see the benefits of utilizing drones in their operations as they may be under the impression that any benefits the technology could bring them might not be greater than the cost of the service,

while large-scale producers are justified in the use due to economies of scale. As shown throughout this paper, the information gathered by agricultural drones can reduce costs and significantly assist farmers in optimizing their farms no matter their size be it by discovering undetected diseases, pinpointing leak locations, assessing drainage issues, or assessing irrigation efficiency.

The study further documents that awareness of the product is not the reason why agriculturalists are hesitant about adopting precision technology. The IFAMA found that more than 75% of the farmers sampled were aware that drones can be adopted in agriculture and that they can be utilized to, "*to evaluate plant health and monitor disease or insect outbreaks*" (Skevas et all., 2019, p.474). Fewer agriculturalists, "*56 and 62% respectively*", were knowledgeable about the fact that drones could also be utilized to, "apply agrochemicals or monitor plant hydration and nutrient uptake" (Skevas et all., 2019, p.474). While awareness of drone capabilities among farmers ranges from 56%-75% adoption is still low at 8%, this means that awareness of the technology and its capabilities are not the reason adoption in this field is lagging and that perhaps social stigmas, perceptions about the benefits, and process questions, and cost concerns are at the core of this issue.

When further questioned in the study, the participant farmers, "*stated they were apprehensive about potential privacy concerns their neighbours might harbor over their use of UAVs on their farm*" further prompting by interviewers ultimately uncovered that the statements carried little weight, as the majority of agriculturalists ultimately admitted that their neighbours "would be indifferent" to the use of drones over their farms (Skevas et all., 2019, p.474). The initial approach of the interviewed subjects to use an unfounded claim to explain their hesitancy to adopt speaks to a larger concern of a human desire to stick to the status quo and what has worked overtime to eliminate the potential risk of adopting new methods and the uncertainty surrounding it. Another factor that could play into this hesitancy to adopt is that farmers tend to be more conservative in their political nature, which can reflect in their approaches to approaching new technologies with a skeptical eye (ISPOS, 2006).

While the majority of the sampled farmers were aware that drones could be used in agriculture as well as how they could be applied to the farming process, the subjects were not convinced about the benefits that agricultural drones could provide them. 83% of the farmers interviewed by the IFAMA, "*did not perceive that the use of UAVs can reduce farm input costs*" (Skevas et all., 2019, p.474). An additional 65% of the subjects did not think drone technology could have any positive environmental impacts on the farming process.

Finally, the last areas of contention for farmers were regarding, "*initial costs of acquiring UAVs, the knowledge required to operate them, the assistance needed to process and interpret the data collected through UAVs*" (Skevas et all., 2019, p.474). For simplicity, the before-mentioned categories will be segmented by cost and process. Regarding cost, the farmer's attitudes are understandable because the Agri-Drone industry is developing and pricing information is not available to the consumer without reaching out and booking a consultation. This asymmetry of information, coupled with the before-mentioned factors such as the conservative attitudes of farmers is a great hindrance to the industry and must be corrected if more conversions are expected.

The study demonstrates that while many farmers are aware of the technology, they are uninformed or misinformed about the reality of agricultural drones. It is up to the drone companies and advocates of the industry to communicate and demonstrate the benefits of this technology to eliminate any doubt in the minds of the farmers. This can only be done without reach, transparency, and proof of concept.

Current Developments in Application

California Vs British Columbia

California is known to be a state with some of the most extreme weather in North America. From wildfires, droughts, and floods California experiences a wide range of weather systems which have considerable effects on agriculture in the state. "*Being the fourth largest wine producer in the world*", California has a significant demand to fill and must remain competitive in order to maintain its global position (Singapore Winevault, 2023, pg.1). Having demand and expectations to meet, wineries in that state have adopted the use of agricultural drones in an effort to optimize their farm's effectiveness and resilience to extreme weather elements. This enables them to act on the most accurate and recent information in order to fortify and streamline their operations. While data and research on the impacts that drone monitoring has made on Californian wineries is still emerging, having a detailed understanding of the health of one's crops, irrigation efficiency, disease infestations, and more will undoubtedly lead to a more optimal and robust operation.

Similarly to California, the province of British Columbia is globally renowned for its wine industry. Having a $2.8 billion impact on the economy of British Columbia, wineries and orchards are significant contributors to the economic prosperity and opportunities of British Columbians and Canadians as a whole (British Columbia, 2017). Agriculturalists in British Columbia deal with similar climate challenges such as frequent wildfires and extreme heat waves (Alila et al.,2022). In turn, such climate realities make practices such as water management and crop scouting all the more critical, as any flaw in farming operations can have catastrophic effects on crop yields. A significant difference between the two regions is that Californian agriculturalists have resorted to precision agriculture to optimize their farm management practices, minimizing the negative effects of climate change on their operations. While there are some BC growers that utilize drone services for reliable and actionable data, the popularity of the technology lags significantly in comparison to that of California.

Research into the effectiveness and impact of agricultural drones in California is still emerging as the adoption of the technology was rather recent. Data that will be released can give British Columbian agriculturists a comparative understanding as to what types of benefits can be seen and expected from using drones in a similar climate. The absence of data and studies should not be a detractor for farmers considering adopting drone technology to optimize their businesses. The capabilities of drones and the value of the different types of data they can deliver are established and have been demonstrated repeatably.

Next Steps for Adoption

As highlighted in the previous section, some farmers are hesitant to implement drone programs in their operations because they are unsure about the cost-benefit relationship. Furthermore, farmers require actionable information to ensure the efficient management of their operations.

Above Sensing Ltd began researching the possible applications of multispectral imagery and vegetation indices for overall plant health qualification. One of the main learnings from this research is that the crop models needed to accurately and precisely identify crop issues require multi-year studies. Currently, multi-crop models for plant health assessment do not exist, and the current research focuses on specific crops. This is why a local approach that is guided by agricultural producers could ensure that the research being carried out by local academia and technology organizations has a positive impact on their growing abilities.

The Issue of Cost

Smaller agricultural producers adopted drone monitoring technologies at lower rates than large-scale and industrialized farmers (Skevas et al., 2019). This was due to the fact that they perceived the benefits from drone services as insignificant since they were not informed about the many avenues in which an agricultural drone can assist their operations. Data gathered by drones regarding a farm's operation can benefit even the smallest producers but depending on the profitability of the crop and the average output, the costs of hiring a drone service to attain high-value data, may not be in the financial interest of the smaller agricultural farmer. While in the long term, the benefits that drone-provided data can bring the farmer are undeniable, today's economical volatility may dissuade certain agriculturalists from investing in such services. (Singh et al., 2022).

Above Sensing's Approach to Resolve Cost Hesitancy

In an effort to find solutions to this issue and ensure small-medium scale agriculturalists are able to benefit from drone services, a co-op/subscription model would be a potential solution. Such a structure would distribute the costs of the service among all who sign up in a quantifiable and fair manner, reducing individual costs, while delivering farm-specific and actionable data to stakeholders. Considering that average drone service costs can be as high as $2000 per day, depending on the applications, a method to distribute such a figure fairly among farmers will enable higher adoption rates of such programs. This will ensure an approach towards improving a farm's efficiency that is affordable and available to farms of all sizes and needs.

Sharing the costs of such a service between a group of localized farmers would have no effect on the veracity of the data collected. It would be segmented based on the property lines of the farms and shared with appropriate parties to ensure confidentiality and fairness. The singularity of a flight and the number of farms scanned have no effect on the types of data that can be collected and shared with farmers. From zoning concerns to leak detection and crop

health monitoring, clients will be delivered data that is relevant to their specific farming operation giving them the best possible information to take action and optimize.

Bibliography

Agricultural Drone: A Machine With Its Own Mind. (2021). AGRI MECH, NA. **https://link-gale-com.okanagan.idm.oclc.org/apps/doc/A683024682/ITBC?u=kelo91364&sid=ebsco&xid=a6cc32fb**

Agriculture, Technology, and Business Market. (2019). *Crop Scouting: Definition, Using Apps and Drones for Crop Scouting*. https://www.agrotechnomarket.com/2019/05/crop-scouting.html

Aktar, W. Chowdhury, A Sengupta, D. (2009). Impact of pesticides use in agriculture: their benefits and hazards. *Interdiscip Toxicol*. 2009 Mar;2(1):1-12. doi: 10.2478/v10102-009-0001-7. PMID: 21217838; PMCID: PMC2984095.

Alexov, E. (2006). Canadian Farmers Support A Conservative Government. Ipsos. https://www.ipsos.com/en-ca/canadian-farmers-support-conservative-government

Antognelli, S. (2020). Drones and satellites: Which to choose for agriculture? *Agricolus*.https://www.agricolus.com/en/drones-and-satellites-which-to-choose-for-agriculture/

British Columbia. (2021). *British Columbia Agriculture in Brief.* https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/agriculture-and-seafood/statistics/census/census-2021/2_-_bc_profile_2021_final.*pdf*

British Columbia. (2022). *Nutrient Management.* https://www2.gov.bc.ca/gov/content/industry/agriculture-seafood/agricultural-land-and-environment/soil-nutrients/nutrient-management/nutrient-management-plans

Center for Preventative Action. (2023). War in Ukraine. *Global Conflict Tracker*. https://www.cfr.org/global-conflict-tracker/conflict/conflict-ukraine

Cho, R. (2022). How Climate Change Will Affect Plants. *Columbia Climate School*. https://news.climate.columbia.edu/2022/01/27/how-climate-change-will-affect-plants/

Climate Data Canada. (2023). *Drought and Agriculture*. https://climatedata.ca/case-study/drought-and-agriculture/

Cooper, J. Dobson, H. The benefits of pesticides to mankind and the environment. *Crop Production*, Volume 26, Issue 9, Pages 1337 – 1348. https://www.sciencedirect.com/science/article/abs/pii/S026121940700097X

Coughlin, A. (2021). As Fertilizer Prices Grow, Farmers Could Face Tough Decisions. *Open Markets. https://www.cmegroup.com/openmarkets/agriculture/as-fertilizer-prices-grow--farmers-could-face-tough-decisions.html*

Crop Life Canada Staff. (2019). *Field Notes – Precision Agriculture*. https://croplife.ca/field-notes-precision-agriculture-canada/

Dehaven, A. (2022). Drones working to detect crop disease early, propel ag research forward. https://www.sdstate.edu/news/2022/08/drones-working-detect-crop-disease-early-propel-ag-research-forward

Delaplane, K. (1996). Pesticide Usage in the United States. *The University of Georgia*. https://people.forestry.oregonstate.edu/steve-strauss/sites/people.forestry.oregonstate.edu.steve-strauss/files/PestUse1996.pdf

Dorff, D. Beaulieu, M. (2011). Feeding the soil puts food on your plate. *Statistics Canada*. https://www150.statcan.gc.ca/n1/pub/96-325-x/2014001/article/13006-eng.pdf

Elkin, E. (2021). Nitrogen Shortage to Force U.S. Farmers to Scale Back Fertilizer, CF Says. Bloomberg.Com, 1. https://search.ebscohost.com/login.aspx?direct=true&db=bth&AN=153425535&site=eds-live&scope=site

Environment And Climate Change Canada. (2020). A Healthy Environment and a Healthy Economy. https://www.canada.ca/en/environment-climate-change/news/2020/12/a-healthy-environment-and-a-healthy-economy.html

Environment and Climate Change Canada. (2022). *2030 Emissions Reduction Plan – Canada's Next Steps for Clean Air and a Strong Economy*. https://www.canada.ca/en/environment-climate-change/news/2022/03/2030-emissions-reduction-plan--canadas-next-steps-for-clean-air-and-a-strong-economy.html

Farms.com. (2022). Precision Technology Uses in Crop Scouting. https://www.farms.com/precision-agriculture/crop-scouting/

Fernández-Luqueno, F., & López-Valdez, F. (2014). Fertilizers: Components, Uses in Agriculture and Environmental Impacts. *Nova Science Publishers, Inc. https://novapublishers.com/shop/fertilizers-components-uses-in-agriculture-and-environmental-impacts/*

Global Insight 2023 Outlook: Canada. (n.d.). https://www.rbcwealthmanagement.com/en-ca/insights/global-insight-2023-outlook-canada

Grain farmers of Ontario. (2022). Farm Groups and the Fertilizer Industry Call on Government to Support Farmers After Impact of Russian Tariff. https://gfo.ca/news-releases/farm-groups-and-the-fertilizer-industry-call-on-government-to-support-farmers-after-impact-of-russian-tariffs/

High resolution aerial imagery for large areas. (n.d.). *Wingtra*. Retrieved March 31, 2023, from. https://wingtra.com/mapping-drone-wingtraone/image-quality/

Institute of Agriculture and Natural Resources. (2015). WWII Nitrogen Production Issues in Age of Modern Fertilizers. *University of Nebraska – Linclon*. https://cropwatch.unl.edu/fertilizer-history-p3

Jenkins, S. (2022). How the Russia-Ukraine War Helped Fuel Record Fertilizer Prices. *Federal Reserve Bank of St. Luis*. https://www.stlouisfed.org/publications/regional-economist/2022/oct/russia-ukraine-war-record-fertilizer-prices

Koh, D. (2020). COVID-19 lockdowns throughout the world. *Occupational Medicine*, Volume 70, Issue 5, Page 322. https://doi.org/10.1093/occmed/kqaa073

Krapez, J. C., Sanchis Muñoz, J., Mazel, C., Chatelard, C., Déliot, P., Frédéric, Y. M., Barillot, P., Hélias, F., Barba Polo, J., Olichon, V., Serra, G., Brignolles, C., Carvalho, A., Carreira, D., Oliveira, A., Alves, E., Fortunato, A. B., Azevedo, A., Benetazzo, P., . . . Le Goff, I. (2022). Multispectral Optical Remote Sensing for Water-Leak Detection. *Sensors*, 22(3), 1057. https://doi.org/10.3390/s22031057

March, J. (2020). Sustainable Irrigations Systems to Reduce Water Waste. https://environment.co/sustainable-irrigation-systems-to-reduce-agricultural-water-waste/

McKenzie, R. (2017). Scouting your fields – what you should know. *Top Crop Manager*. https://www.topcropmanager.com/scouting-your-fields-20061/

Ministry of Agriculture and Food. (2021). British Columbia Agriculture in Brief 2021. https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/agriculture-and-seafood/statistics/census/census-2021/2_-_bc_profile_2021_final.pdf

Ministry of Agriculture, Food and Fisheries. (2020). 2020 B.C. Cherry and Apple Acreage Report. https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/agriculture-and-seafood/animal-and-crops/crop-production/2020_bc_cherry_apple_acreage_report.pdf

Ministry of Agriculture. (2015). *IRRIGATION TIPS TO CONSERVE WATER ON THE FARM. WATER CONSERVATION FACTSHEET.* https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/agriculture-and-seafood/agricultural-land-and-environment/water/irrigation/500310-1_irrigatiion_tips_to_conserve_water.pdf

Mohanty, S. Hughes, D. Salathe, M. (2016). Using Deep Learning for Image-Based Plant Disease Detection. *Sec. Technical Advances in Plant Science,* Volume 7 – 2016, https://doi.org/10.3389/fpls.2016.01419

OECD. (2017). Managing water sustainably is key to the future of food and agriculture. https://www.oecd.org/agriculture/topics/water-and-agriculture/

Pimentel, D. (1995). Amounts of pesticides reaching target pests: Environmental impacts and ethics. Journal of Agricultural and Environmental Ethics, Volume 8, Pages 17-29. https://link.springer.com/article/10.1007/bf02286399

Pimentel, D., Burgess, M. Small amounts of pesticides reaching target insects. *Environ Dev Sustain* 14, 1–2 (2012). https://doi.org/10.1007/s10668-011-9325-5

Ristaino, J. Anderson, P. Bebber, D. Wei, Q. (2021). The persistent threat of emerging plant disease pandemics to global food security. https://doi.org/10.1073/pnas.2022239118

Skevas, T., & Kalaitzandonakes, N. (2020). Farmer awareness, perceptions and adoption of unmanned aerial vehicles: Evidence from Missouri. *International Food and Agribusiness Management Association.*23(3):1-18DOI:10.22434/IFAMR2019.0151

Snyder, C. Bruulsema, T. Jenson, T. Fixen, P. (2009). Review of greenhouse gas emissions from crop production systems and fertilizer management effects. Volume 133, Issues 3–4, Pages 247-266. https://doi.org/10.1016/j.agee.2009.04.021

SOWIT. (2022). Satellites or Drones for precision agriculture? SOWIT I Ag Intelligence. https://www.sowit.fr/2022/07/28/satellites-or-drones-for-precision-agriculture/

Statistics Canada. (2014). Environment Fact SheetsIrrigation methods and conservation practices on Canadian farms, 2014.https://www150.statcan.gc.ca/n1/pub/16-508-x/16-508-x2016001-eng.htm

Statistics Canada. (2020). Agricultural Water Survey, 2020. https://www150.statcan.gc.ca/n1/en/daily-quotidien/211213/dq211213d-eng.pdf?st=NIqZFKcF

Statistics Canada. (2023). *Farm input price index, quarterly*.
https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1810025801&pickMembers%5B
0%5D=1.1&cubeTimeFrame.startMonth=01&cubeTimeFrame.startYear=2020&cubeTim
eFrame.endMonth=10&cubeTimeFrame.endYear=2022&referencePeriods=20200101%2
C20221001

Times Agriculture. (2022). Drone Technology in Agriculture. *https://timesagriculture.com/drone-technology-in-agriculture/*

Trading Economics. (2022). *Canada - Fertilizer Consumption (kilograms Per Hectare Of Arable Land)*.https://tradingeconomics.com/canada/fertilizer-consumption-kilograms-per-hectare-of-arable-land-wb-data.html

Trading Economics. (2022). *Canada Imports from Russia.*
https://tradingeconomics.com/canada/imports/russia

UBC experts on heat waves and extreme heat. (2017). *UBC News*.
https://news.ubc.ca/2022/08/17/ubc-experts-on-heat-waves-and-extreme-heat/

United States Environmental Protection Agency. (2020). Climate Change Indicators: Length of Growing Season. https://www.epa.gov/climate-indicators/climate-change-indicators-length-growing-season

United States Environmental Protection Agency. (2022). Why We Use Pesticides. *EPA*.
https://www.epa.gov/safepestcontrol/why-we-use-pesticides

University of Guelph. (2016). Precision agriculture. *Research*.
https://www.uoguelph.ca/research/sites/default/files/public/Research_PrecisionAg_4pager_Web.pdf

Unmanned aerial vehicles. (2020). Evidence from Missouri. International Food and Agribusiness.
https://www.wageningenacademic.com/doi/abs/10.22434/IFAMR2019.0151

Wingtra Knowledge Base. (2022). *Flight time, coverage and job time with the WingtraOne*.
https://knowledge.wingtra.com/en/flight-time

Woznicki, S. Nejadhashemi, A. Parsinejad, M. Climate change and irrigation demand: Uncertainty and adaptation. *Journal of Hydrology: Regional Studies*. Volume 3. Pages 247-264.
https://doi.org/10.1016/j.ejrh.2014.12.003

Xue, J., & Su, B. (2017). Significant Remote Sensing Vegetation Indices: A Review of Developments and Applications. *Journal of Sensors*, 2017, 1–17.
https://doi.org/10.1155/2017/1353691

YCharts. (2022). *Fertilizers Price Index*.
https://ycharts.com/indicators/fertilizers_index_world_bank

YCharts. (2022). *Food Price Index*. https://ycharts.com/indicators/food_index_world_bank