App-based Food Loss Quantification: Farmers' Perspectives on the Role of Digital Agriculture in southwestern British Columbia

by

Alexander Hook

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Declaration of Committee

Name:	**Alexander Hook**
Degree:	**Master of Resource Management (Planning)**
Project No.:	**783**
Title:	**App-based Food Loss Quantification: Farmers' Perspectives on the Role of Digital Agriculture in southwestern British Columbia**
Committee:	**Chair: Elina Blomley** Master of Resource Management Candidate, Resource and Environmental Management
	Tammara Soma Supervisor Assistant Professor, Resource and Environmental Management
	Belinda Li Committee Member Research Assistant , Resource and Environmental Management

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Abstract

Food loss is a systemic problem contributing to negative environmental, social, and economic impacts. Digital agriculture technologies (DAT) such as farm apps may provide a useful method for quantifying food loss and therefore help reduce and prevent food loss. To assess the potential role of DAT for food loss quantification, seven farmers in southwest BC tested a farm management app called LiteFarm and digitally recorded their harvest logs. Drawing upon semi-structured key informant interviews, this study found that time scarcity was one of the major barriers to using the app. An unexpected benefit to the app is that DAT can better inform land use decisions when utilized for pre-harvest planning. Findings from this study highlight farmers' struggles to focus on sustainability and reducing food loss, especially when balancing economic interests. Inclusive technologies and deeper engagement with farmers are needed to develop food loss quantification methods that fit diverse farming contexts.

Keywords: Digital Agriculture; Food Loss; Technology; App-based Management; Quantification

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List of Acronyms

ALC	Agricultural Land Commission
ALR	Agricultural Land Reserve.
CSA	Community Supported Agriculture
DAT	Digital Agriculture Technology
FAO	Food and Agriculture Organization of the United Nations
FLW	Food Loss and Waste
FSC	Food Supply Chain
UBC	University of British Columbia

Chapter 1. Introduction

Supply chain issues, economic hardships, the Covid-19 pandemic, and disruptive climate events have shocked our global food system and demonstrates its precarity and systemic injustices (Clapp & Moseley, 2020, Béné, 2020; Wheeler & Von Braun, 2013). While the pandemic has resulted in increasing food insecurity (Devereux et al., 2020), farmers globally were faced with disruptions that resulted in massive wastage (Aldaco et al., 2020; Fei et al., 2020; Food and Agriculture Organization of the United Nations, 2020). For example, in the midst of the pandemic, the dairy sector saw 3.7 million gallons of milk (5% of the USA's milk supply) dumped each day and roughly 750,000 unhatched eggs smashed every week (Yaffe-Bellany & Corkery, 2020). With the loss of restaurant, hotel and school food demands, farmers have lost half their customer base, resulting in food being tilled under due to cancelled orders (Hobbs, 2020; Yaffe-Bellany & Corkery, 2020). In Canada, avoidable food loss amounts to 6.1 million tonnes, excluding food waste from the retail and consumer sectors. This equates to roughly 17 percent of Canada's total food loss and waste (FLW), and is valued at 26.3 billion dollars annually (Nikkel et al., 2019).

FLW can be broken down into two separate concepts, "food loss" and "food waste". While there are differing definitions, "food loss" generally describes food that is lost in the production, post-harvest, and processing stages, up to but not including retail (FAO, 2019). "Food waste" is food that is wasted from the retail stage to the consumer level (FAO, 2019). Many scholars have identified inconsistencies and potential confusion with FLW definitions citing gaps related to pre-harvest losses, criteria for "edible food", and environmental or social considerations (Chaboud & Daviron, 2017). Measuring food loss and providing standardized estimations across the globe remains a glaring gap in food systems research. Roe (2020) argues that there are still numerous issues and confusion around food loss measurement methodology. There are few quantitative studies measuring food loss on farms in comparison to food waste measurements. The studies that do attempt to measure food loss (Delgado et al., 2017; Sheahan & Barrett, 2017; Johnson et al., 2018) utilize varying methods, thus limiting the ability for data comparison. Divergent methods for measuring food loss have produced conflicting results and scholars have called for more standardization in food loss quantification methodology. Furthermore, even when farmers are given the opportunity to measure food loss, participation is difficult. An example being Hartikainen et al’s study (2018) where they did not report their quantitative food loss data as the sample sizes were too low to be conclusive. The potential causes for minimal food loss data included lack of time for collection and extenuating circumstance such as weather events or shifts in retail demand (Hartikainen et al., 2018).

Addressing inconsistent food loss measurement methodologies can provide the foundation for developing evidence-based interventions to increase economic, environmental, and social benefits to farmers and subsequent stakeholders in the food supply chain. There are numerous causes for food loss generally related to human error, equipment function and weather/climate factors (Johnson et al., 2018) as well as demand side reasons including food aesthetics and retail/consumer choice (Soma et al., 2021). Food loss remains a pressing issue globally although studies have disproportionately framed this issue as predominant to the global south. However, FLW in Canada alone totals roughly 35.5 million metric tonnes of every year which equates to 56.5 million megatons of CO2 and roughly 49.5 billion dollars in damage costs annually (Nikkel et al., 2019). Canada’s FLW management policy lags behind many European Union nations such as Italy and France which have comprehensive reuse and recovery laws compared to Canada’s sporadic landfill regulations and municipal bans (Giordano, 2020). Understanding food loss as a systems issue may support further research that properly incorporates issues at a farm level.

One potential solution proposed to facilitate the ease of quantifying food loss is digital agriculture. In the realm of FLW, Benyam et al (2021) explores the potential applications of Digital Agriculture Technology (DAT) on FLW prevention and reduction. DAT tools include GPS simulations for optimal distribution routes, digital marketing campaigns that improve consumer awareness, nanotechnology that supports precision agriculture and more. Therefore, there is potential that digital agriculture can support novel techniques for FLW prevention and reduction. DAT has been touted by proponents as potentially positioning the Canadian agricultural industry as a global leader in safe, nutritious and sustainable food in the 21st century (Bronson & Knezevic, 2016; Advisory Council on Economic Growth, 2017). DAT includes technology that can be used to track farm data efficiently and therefore has the potential to improve the accuracy of food loss measurement (Klerkx & Rose, 2020). However, FLW data tracking remains understudied in this digital revolution. Investing in technology that can accurately and efficiently track food waste may result in further advancement in DAT. This technological change may influence better policy towards reducing food waste, encourage better resource management, and therefore promote a more sustainable food system.

Recognizing the growing investments by governments and financial institutions in digital or “smart” technologies, this study seeks to understand the perception, adoption, and engagement, of DATs by farmers in British Columbia (B.C) as well as their potential role in food loss quantification. This study analyzes farmers’ use and their feedback of an open-source farm management app called LiteFarm. LiteFarm was designed by UBC to measure the environmental impact (water use, energy use, inputs) of diverse types of farm management. LiteFarm can also be used to measure food loss by facilitating manual data entry in a harvest log feature. In this study, we train farmers to measure their post-harvest food loss and farm yield with this app. The purpose of this study is to better understand if digital technologies such as apps can help facilitate ease in the measurement of post-harvest waste. This is an exploratory study of (n=7) farmers in two differing communities (conventional and organic) in southwestern British Columbia and their use of the LiteFarm app for a period of 2 months.

The following are the primary research questions and sub questions for this study:

1. What is the potential role of digital agriculture tools (in this study: the use of LiteFarm app) for facilitating food loss measurement on farms?
2. What barriers and opportunities exist within the adoption of digital agriculture technologies that could better support food loss quantification, prevention, and reduction at the farm-level?

This study will contribute to the discussion around the growing use of DAT and its current role in our global food systems. In learning more from the farmers about their experience with using app-based DAT for food loss measurement, this study can contribute to the literature addressing the potential social, environmental, and economic implications of DAT. There is currently a gap in the literature on empirical studies demonstrating the impact of DAT on FLW prevention and reduction, with most studies focusing on estimated potential (Shepherd et al., 2020; Benyam et al., 2021). Therefore, this study will introduce new findings that may provide insights on the use of DAT in the FLW realm.

The following chapter (Chapter 2: Literature Review) covers key themes that are relevant to the study, namely food loss at the farm level, food loss quantification and challenges, and the role of digital agriculture. Chapter 3 focuses on methods and frames the study around the use of LiteFarm by the farmers. Chapter 4 contains the findings of the study. Chapter 5 will discuss the findings with relation to agricultural literature and suggest recommendations based on the findings. Finally, chapter 6 will conclude this paper.

Chapter 2. Literature Review

2.1. Food Loss at the Farm Level

The Food and Agriculture Organization of the United Nations (FAO) estimates around one third of the world's food is lost or wasted every year (FAO, 2019). This estimate includes food at all levels in the food supply chain (FSC) from production to consumption. FLW has been calculated with inconsistent measurements for years (Chaboud & Daviron, 2017). However, recent attention given to fresh produce loss at a farm level (Johnson et al., 2018; Alexander et al., 2017) has highlighted the need for further study related to farm level food loss, specifically food loss quantification. Measurement and challenges related to food loss quantification will be explored in the following section, specifically the literature addressing food loss at a farm level, where these studies are occurring and what are some causes of food loss.

Initial misconceptions exist related to the use of the terms "food loss" versus "food waste" which are commonly combined or used interchangeably in many studies. Definitions for "food loss" are generally associated with pre-harvest, post-harvest, and processing stages in the FSC (Lipinski et al., 2013; Chaboud & Daviron, 2017), as well as harvest, slaughter, catch, and unintentional equipment or infrastructure issues impacting edible food meant for human consumption (FAO, 2019; Feedback, 2021). While the terms "food loss" and "food waste" are often used interchangeably, there is an important distinction to be made especially when considering actions taken at the producer level (Gustavsson, 2011). Producers may be encouraged to reduce their FLW (Chaboud & Daviron, 2017), yet there are conditions that are out of a producer's control such as quality loss during distribution, environmental impact, or aesthetic standards at retail outlets, that can overburden the producers and result in ineffective interventions (Gustavsson, 2011; Chaboud & Daviron, 2017).

FLW measurements remain problematic due to variable estimates among commodity groups and difficulty when collecting current data. Estimates made by the FAO (2019) place global food loss at roughly 14% before reaching the retail stages. Fruits/vegetables and tubers/root vegetables see the highest food loss numbers with the global average being roughly 22% of fruits and vegetables lost per year and 25% of tubers and root vegetables lost per year (FAO, 2019). It has been documented that current food loss statistics suffer from highly extrapolated data and outdated average values to generalize regional food loss situations (Johnson et al., 2018). Gustavsson et al (2011) reports a global average food loss of 20%, however, Johnson et al (2018) reported estimated food losses in North Carolina that are much larger. Johnson et al (2018) acknowledges that their estimates include both marketable and edible food which would require additional measures including consumer acceptance and available FSC capacity fully value. Food loss metrics from Johnson et al's (2018) study include a 12% marketable yield loss for one of the squash fields, a 143% loss for one of the cucumber fields and an average marketable yield loss of 57% for all fruit and vegetable fields in the study. Neff et al. (2018) studied food loss on farms in Vermont and found that 16% of food loss was considered salvageable, comparable to Gustavsson et al (2011), however, Neff et al's (2018) combined unharvest metrics which follow Johnson et al's (2018) method, found 30% loss on the field as their average marketable food loss metric. Food loss studies can report results under many different labels, including terms such as marketable, saleable, and edible which incorporate similar characteristics, but are not always interchangeable Therefore, clear food loss definitions are important when interpreting results.

Food loss at a farm level is predominantly driven by misguided subsidies, market power imbalances, and reliance on precarious migrant workers (Soma et al., 2021). North American farmers have subsidies available that may drive overproduction (Soma et al., 2021). For example, the market price for a given produce may decrease seasonally and if subsidies require a certain percentage of this produce to be harvested year-round, a farmer may leave crops unharvested due to low market value. Similarly, there is power imbalance within the consumer and retail food market (Soma et al., 2021; Feedback, 2021). Canada has only five grocery stores commanding nearly 80% of the food retail market (Soma et al., 2021) and within those retail markets, consumer choice dominates market value, highlighting strict aesthetic standards and social food norms in North America (Janousek et al., 2018). Food loss at a farm level is also associated with the instability in agricultural labour forces (Soma et al., 2021). Agricultural operations generally rely on migrant temporary workers as a significant percentage of their labour force causing uncertainty for potential harvesting numbers (Janousek et al., 2018). Given the labour instability and market volatility, some farmers have acknowledged that they overproduce in an attempt to minimize their financial risks (Gunders & Bloom, 2017). However, other food loss studies refute this point as many farmers also rely on historical observations and tested experience to minimize financial hardship (Johnson et al., 2019).

Until recently, there has been a perception that developing countries have issues more commonly associated with food loss such as lack of infrastructure, while developed countries are associated with consumer food waste issues (Gustavsson et al., 2011; Parfitt, 2010). Only recently did the United Nations Environmental Programme (2021) acknowledged the problem of putting the emphasis of food loss studies in developing countries. Not only does this overlook similar food loss problems occurring in developed nations, but it also results in solutions that are not aligned with any farmer's true needs (Soma et al, 2021). Food loss reduction and prevention methods should reflect studies in appropriate settings to avoid mismanaged farms and exacerbating problems. Riches (2018) describes the problem with solutions for food loss reduction that are based on donating to food banks as these are superficial solutions to systemic problems of poverty and hunger.

Food loss management has two distinct paths, reduction, or prevention. Messner (2020) draws attention to the plethora of studies looking at food loss reduction measures (Lipinski et al., 2013; Shafiee-Jood & Cai, 2016; Verma et al., 2017) that neglect the potential for a proactive approach to tackle the root causes of food loss. Unfortunately, food loss policies in Canada have focused narrowly on landfill bans or tax incentives for food donation (Soma et al., 2021) while more effective policies for "zero waste" are being pushed in China and the EU including agricultural carbon sequestration policies and bio based renewable energy standards (Zacho et al., 2016). There are significant challenges for food loss prevention and reduction including structural issues such as unfair trading practices (UTP) (Piras et al., 2018). UTPs result from a power imbalance in a FSC between major retailers and producers which results in costs and risks shifted unfairly to one party (Piras et al., 2018). These major retailers can cancel orders or shift their demands without advanced notice for producers, putting farmers under significant financial pressure (Piras et al., 2018). The food system should identify and avoid UTPs by outlining fair contracts which support retailer/producer relationships and prioritize requirements for FLW reduction and prevention (Piras et al., 2018). Donation tax incentives are another challenge for farmers attempting to address food loss prevention and reduction. Kinach et al (2019) explores the challenges with donation tax incentives including the moral perception of food donations as a solution to food insecurity and the logistical issues that come from perishable food donation programs. While there are challenges to reducing and preventing food loss, surplus food can be valuable through established interventions including community kitchens, supporting school food programs, food bank gleaning partnerships and food donation centers (Soma et al., 2021).

2.2. Food Loss Quantification and Challenges

Quantifying food loss remains a complex challenge that involves time intensive measuring techniques with little incentive for busy farmers. Kitinoja et al., (2018a) explored post-harvest loss assessments for plant-based crops and found the range of losses between different crop types was substantial. For example, loss of legumes and grains range from 0-40 percent while other non-perishable food losses range from 0-80 percent in some cases. This discrepancy is due to the lack of quantitative food loss data collected from farm sites as studies more frequently collect qualitative data to estimate food loss (Kitinoja et al., 2018a). The lack of quantitative field data collection makes standardization challenging which could explain the literature gap around food loss quantification (Kitinoja et al., 2018a). In a similar synthesis paper, Kitinoja et al. (2018b) directly address challenges to food loss quantification seen in their previous study and other relevant literature. Lack of clarity around the definition of food loss (Chaboud & Daviron, 2017), data gaps for FLW in specific regions (Gustavsson, 2011) and a lack of standardization of methodologies across studies (Kitinoja, et al., 2018a) were identified as key challenges for collecting accurate food loss quantification data.

A standard for food loss quantification is a four-step process outlined by the FAO in a 2016 methodology document. The steps include screening, survey, sampling, and synthesis to collect both qualitative and quantitative food loss data at the farm level (FAO, 2016). The concerns with this method arise within the biases for sampling and surveying; since the document instructs researchers to use “highly knowledgeable actors in the FSC to create their specific method for surveying and sampling” (FAO, 2016, pg. 4). The FAO’s methodology provides a comprehensive framework for identifying specific food loss events; however, it would be difficult to extrapolate with a broad scale approach. While a roadmap document such as the FAO’s (2016) is important for starting the process of standardizing food loss quantification, it does not address inconsistencies outlined by food loss literature. The important inconsistencies include the lack of clarity in the definition of food loss (Chaboud & Daviron, 2017), issues with defining specific areas on the farm that will be subject to measurement (Chaboud & Daviron, 2017), and communication among several FSC actors that will be involved in a given food loss measurement (Gustavsson et al., 2011). A study by Johnson et al (2018) measured food loss at nine farms in North Carolina and presented their results in a kilogram per hectare measure of food loss (Johnson et al., 2018). Their study utilized a physical sampling method and looked at quantity, quality, and condition to categorize food into marketable, edible, or inedible standards (Johnson et al., 2018). The results displayed an average of 5114 kilograms per hectare of food was available after the primary harvest, equating to an average harvest loss of 57 percent (Johnson et al., 2018) It was acknowledged that these results are high and given the current information gap regarding food loss measurement there is a need for reevaluation (Johnson et al., 2018). Johnson et al (2018) concluded that the information gap is not from the lack of ability by food researchers to measure losses, but rather a lack of human capital to undertake quantitative food loss measurements. The food loss measurement methods utilized by Johnson et al (2018) focused on mass recovery and detailed post-harvest sorting which is time intensive. Other scholars suggest alternative methods with pre-harvest organization or on field estimates to lower time commitments (Kitinoja et al., 2018a).

Food loss quantification literature has also questioned the characteristics used to define inedible or unmarketable food. The FAO (2016) uses the terms inedible and unmarketable to describe types of food losses in their definition, however, these terms can be subjective especially when interacting with producers (Chaboud & Daviron, 2017). Inedible is generally used for parts of food that cannot be eaten (e.g., certain livestock skins, fish bones) while unmarketable refers to a consumer demand preference related to quality or condition (FAO, 2016). An inedible food is almost immediately defined as a physical or quantitative loss while unmarketable foods may take time to evaluate and are referred to as a qualitative loss (FAO, 2016). Using both qualitative and quantitative definitions for food loss, the FAO’s (2016) quantification method captures themes of food safety as well as economic viability to determine whether food is saleable. Unfortunately, Johnson et al (2018) highlights how this subjective researcher-producer relationship can generate distrust and creates a future divide when producers are asked to participate in new food loss studies.

Accurate food loss quantification could lead to better agricultural techniques and FSC efficiency. Gillman et al (2018) concluded that on farm food losses were driven by economic mitigation strategies and that farmers are constantly balancing an equilibrium between environmental concerns, economic situations, and social opportunities when dealing with their surplus harvest. Sheahan & Barrett (2017) and Gillman et al (2018) would both agree that food loss quantification should expand its scope to consider other factors in an agricultural operation such as alternative markets for surplus food (Soma et al, 2021), collaborative efforts between different actors in the FSC (Ciccullo et al., 2021) and techniques that might measure environmental impacts such as methane emissions (Nikkel et al., 2019).

Roe (2020) suggests modelling as a solution to addressing the gap in food loss data. Modelling provides a method that can be applied with significantly less human capital than a traditional physical data collection study and allows for creative flexibility when it comes to including alternative variables such as quality and end use value (Roe, 2020; Delgado et al., 2017). Roe (2020) envisions food loss modelling as a framework towards filling the literature gap given its lower time commitment and replicability. Furthermore, an additional benefit from modelling is testing specific food loss quantification in different sectors of the FSC. Since model parameters can be easily changed they can support testing for complex problem areas such as storage infrastructure or distribution travel time without significant physical testing (Roe, 2020). The end goal with modeling is to find accurate food loss quantification methods that can be replicated in physical data studies (Roe, 2020).

2.3. Role of Digital Agriculture Technology

Digital Agriculture Technology (DAT) has the potential to significantly influence global methods for food loss quantification. However, its contribution to the field of FLW studies is currently understudied, and the potential benefits of DAT for food loss prevention, reduction, and quantification lack empirical evidence. DAT can be defined as any agricultural technology that assists in collecting, storing, analyzing, or sharing data, this includes sensors, data storage, telecommunications, and analytics (Klerkx & Rose, 2020; Shepherd et al., 2020). Measuring food loss quantification can benefit from several common DATs including food traceability technology (Astill et al., 2019; Bosona & Gebresenbet, 2013), predictive planning technology (Nazirul et al., 2020) and precise input applications (Finger et al., 2019). Investment in DAT in the food and farm sector is growing. The digital food and agricultural sector has risen by 80 percent annually from 2012 with global venture capitalist investment in agriculture technology up to $3 Billion in 2015 from 500 million in 2012 (Clercq, et al., 2018). Robotics, low-cost soil sensors, artificial intelligence, and blockchain are all appearing to push the boundaries of possibilities in agriculture and food production (Rossel and Bouma, 2016). Proponents of digital agriculture argue that the scarcity of natural resources, climate change, and a growing population will require significant investment in agricultural technologies to increase productivity and reduce wastes (Clercq et al., 2018). While DAT has received attention for its potential to contribute to climate-friendly and sustainable farming practices, there is a research gap related to its potential for on farm food loss quantification. Two recent studies that have addressed the food loss aspects of DAT are Ciccullo et al. (2021) and Benyam et al. (2021). Ciccullo et al (2021) quantitatively estimates the effectiveness of DAT in the agri-food sector and partnered technology sectors. Benyam et al. (2021) explores the current literature related to food loss and waste quantification and DAT, drawing connections between current technologies and their potential application to prevent or reduce food loss globally.

Ciccullo et al. (2021) studies FLW prevention in the context of a circular economy and is the only study that has recently explored the use of DAT specifically for FLW prevention. This paper looked at technology providers and agri-food supply chain actors to assess the available technology and objectives for preventing FLW. The study found that there are many types of technologies that achieve different results in the food supply chain. These technologies can be broken down into two categories: 1) off the shelf or 2) customizable. Ciccullo et al (2021) emphasizes that technologies work better for FLW prevention if they are customized and suggests a stronger and more collaborative relationship between technology developers and agri-food actors. This will inevitably widen the scope of potential food surplus management strategies introduced by Chaboud & Daviron (2017).

Benyam et al. (2021) conducted a literature review summarizing several important considerations for future research around DAT and food loss quantification. Benyam et al (2021) highlighted that communication among food actors was seen as essential for success in DAT adoption and operation. Communication creates trust and gives an opportunity for innovation with various DATs (Bene, 2019; Ciccullo et al., 2021).

Benyam et al (2021) created Figure 1 (below) to highlight the potential benefits DAT can offer regarding FLW reduction and prevention including market value information, individual crop health statistics, and more. However, the authors caution that the spillover effects, both positive and negative must be considered as farmers choosing to adopt DATs will not necessarily do so with the primary purpose of food loss prevention or reduction (Benyam et al., 2021). DAT for food loss prevention or reduction provides potential benefits, but also include associated costs including upgraded infrastructure (Finger, 2019) and training for the labour force (Rotz, 2019) which may create initial barriers to DAT adoption (Benyam et al., 2021; Klerkx & Rose, 2020). As Benyam et al (2021) concludes, while food loss prevention or reduction may be beneficial, many farmers will not choose to adopt the technologies if it does not directly contribute to their economic output.

Figure 1: Benyam et al (2021) DAT benefits for FLW and prevention

Current food loss quantification research focuses on post-harvest measurement as opposed to pre-harvest planning. Many of the benefits seen from DAT related to food loss quantification have been identified as potentially occurring in the pre-harvest stages (Cicciullo, 2021). The major barriers for DAT adoption are related to poor infrastructure (Finger et al., 2019), and technology gaps for older traditional farmers (Benyam et al., 2021) among others. However, certain barriers could be avoided by switching the emphasis to pre-harvest planning and taking a proactive approach (Chaboud & Daviron, 2017). Real time food loss quantification can be complex and time consuming, therefore, Chaboud & Daviron (2017) propose focusing on pre harvest planning to help farmers proactively identify inefficiencies with their land use practices and reduce or prevent future food losses.

It is important to note that the use of DAT is still contentious among experts. However, some of the major concerns are not inherent to the agricultural field, but rather lie in digitization itself and who controls/owns the data (Carolan, 2017). New agricultural technology may provide increased land use efficiency or decreased labour costs, however, there are also contrasting risks of failure and accessibility concerns (Shepherd et al., 2020). Concerns around data ownership and privacy also threaten DAT adoption and social acceptance within the agricultural community (Carolan, 2017). Large technology or retail corporations that split data ownership with farmers spark worries around technological dependence, as well as decision making anxiety (Carolan, 2017). Farmers may see benefits from DAT but are unwilling to surrender any decision-making power or have their private operations monitored by large influential corporations (Carolan, 2017). An example from Carolan's (2017) study shows that some United States farmers were unable to repair their own equipment due to legal contracts signed with a corporation, however, the equipment's capital costs, and operational costs were still incurred by the farmer. Magruder (2018) and Shepherd et al (2020) both agree that filling the information gap and providing producers with adequate training will help the transition to a digitized agricultural field. Adoption of DAT by farmers for the purpose of FLW prevention and reduction will require supportive policies which will be explored in the final sections of this paper.

Chapter 3. Methods

3.1. Research Context

This study is based in Metro Vancouver, a regional district located in southwestern British Columbia (BC), Canada. Metro Vancouver is on the unceded traditional territories of the Coast Salish People including the Squamish, Musqueam, Tsleil-Waututh, Stó:lō, Semiahmoo, Tsawwassen, Kwikwetlem, Kwantlen, Matsqui, Qayqayt, Hwlitsum, and Katzie nations. According to a 2016 Canada Census, Metro Vancouver has a population of 2.57 million people.

Metro Vancouver was chosen as the study location for its food production diversity, commitment to local food system resiliency and strong stance on supporting DAT (BC Food Security Task Force, 2019). Southwestern BC is located in a temperate rainforest biome, associated with long growing seasons and mild winter conditions (WelcomeBC, 2022). Furthermore, high annual precipitation averages create an opportunity for year-round crop growing in BC's arable lands. Given the rocky, mountainous landscape in southwestern BC, much of the region's arable land is located close to the Fraser River, the longest undammed river in North America, or floodplains closer to the USA-Canada border (WelcomeBC, 2022). BC's climate conditions are comparable to other coastal areas such as New Zealand or England and BC, in general, has diverse agricultural operations from the Okanagan's wine country to the Kootenay's livestock grazing. However, southern BC has a disproportionate amount of the province's population and attempts to grow a variety of crops in objectively poor arable land (BC Ministry of Agriculture, Food and Fisheries, 2016). To account for southwestern BC's poor arable land base many agricultural operations are human engineered meaning they may exist in active floodplains or require significant nutrient additions to remain viable. These operations support the food system, however, they are more vulnerable to climate related damages such as flooding or heat waves and when they are impaired they end up exacerbating social, economic, and environmental impacts already present in our society (BC Ministry of Agriculture, Food and Fisheries, 2021). Southwestern BC's current food system relies on transporting goods from agricultural operations in the Fraser Valley to the city center. Surrey, Langley, and Abbottsford are a few municipalities where much of the food is grown, processed, and distributed (BC Ministry of Agriculture, Food and Fisheries, 2016).

This study focusses on fruit and vegetable crops which make up a small amount of growing opportunity in southwestern BC. There is roughly 2.8% of Canada's field vegetable crops produced in BC, however, 68% of those field vegetables are grown in southwestern BC.as well as almost 55% of fruits and berries (BC Ministry of Agriculture, Food and Fisheries, 2016). Given the relatively small land base in southwestern BC and disproportionate population density, it becomes increasingly important to study how food production can continue under this increased pressure. To avoid continued reliance on a globalized, imported food supply, the provincial government has put in place measures to support local producers with grocery store marketing programs such as BuyBC and land protections such as the Agricultural Land Reserve (BC Ministry of Agriculture, Food and Fisheries, 2022).

The Agricultural Land Reserve (ALR) is protected agriculture land granted by the province of BC; this entails special land use zoning that prioritizes agricultural operations instead of urban development (Provincial Agricultural Land Commission, 2022). The ALR compromises roughly 5 percent of BC's total land base and has been specifically identified by the Agricultural Land Commission (ALC) as biophysically viable and comparably arable to other land area in BC (Provincial Agricultural Land Commission, 2022). To put this in perspective, BC's ALR is mostly comprised in the northern sections with the Peace River and Cariboo regions each holding 29% and the south coast mainland holding only 3.5% of the total ALR land base (Provincial Agricultural Land Commission, 2022). The ALR has a history dating back to 1973 when BC first enacted the *Land Commission Act* to combat erosional land degradation (Provincial Agricultural Land Commission, 2022). Since then, the ALR has been constantly revised to fit more advantageous boundaries, encourage more local farm operations in BC, manage potential environmental changes and combat the societal pressure for more urban development (Provincial Agricultural Land Commission, 2022). The advantage remains that BC farmers can purchase land in the ALR knowing it has been zoned for their production purposes. Recent changes by the ALC have solidified BC's commitment to local farmers by strengthening their position against urban development on the ALR (Provincial Agricultural Land Commission, 2022).

This study utilizes an app called LiteFarm (Wohlers et al., 2021) which was developed at the University of British Columbia (UBC). LiteFarm (see https://www.litefarm.org) was initially developed to support farmers in their pursuit of environmentally friendly practices, however, the app has the potential for overall farm management and record keeping purposes. LiteFarm is not the first occurrence of app-based management in the Pacific Northwest, COG PRO is an organic certified record keeping app that was developed in Oregon and allows for organized notes designed for smaller scale organic farmers. Similarly, Oregon State University has recently developed an app for Community Supported Agriculture (CSA) which connects consumers directly to farmers on a digital interface. CSA programs are popular in southwestern BC and this app has the potential to bridge communication gaps currently found in the local food system. There are several disadvantages in southwestern BC when it comes to quantity of arable land and app-based management may provide small scale farmers with a competitive advantage.

3.2. Methodology

This study secured research ethics approval from the Simon Fraser University Research Ethics Board. There were two components to this study, the first part of the study consisted of training and providing participants with the opportunity to use LiteFarm for a period of approximately two months. There were seven participants in this study including farmers and administrative farm operators. No quantitative data was collected by the researchers; however, food loss records could be utilized by farmers and support for collecting quantitative data was offered. The study's second component was key informant interviews with each participant to assess their experience using LiteFarm. The questions asked pertain to LiteFarm's effectiveness as a farm management app, namely when used to track yield and sales, and as a food loss quantification method. In terms of inclusion/exclusion criteria, this study contacted participants in the Metro Vancouver area that were accessible by motor vehicle and had fruit and vegetable crops that grew during the spring and summer seasons. Fruits and Vegetables were chosen as LiteFarm was not capable of recording livestock records at the time of the study and food loss related to livestock has different causes and effects compared to fruits and vegetables.

The LiteFarm trial period started in April 2021 with online and in-person training sessions. The trial groups were divided into two timeframes to allow for adequate training and site visits. The first group started using the app in May 2021 and ended their trial in July 2021. The second group started in July 2021 and ended their trial in September 2021. Training sessions were led by the researcher utilizing a PowerPoint presentation and practicing with features on the app. Site visits were used to address problems related to the LiteFarm app or for general record keeping. This study looked at food loss quantification and utilized the harvest logs feature (Figure 2,3 & 4) in the LiteFarm app. Harvest logs allow for a farmer to input anything they harvest off the field as well as anything eaten, gifted, or sold.

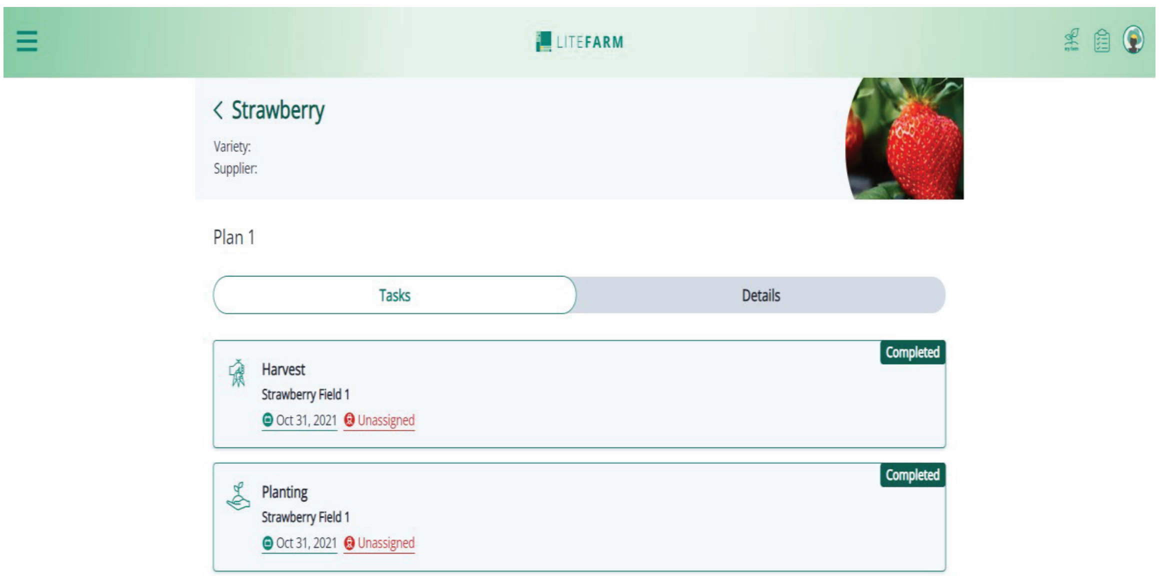

Figure 2: This LiteFarm page depicts the planning page where farmers would add harvest logs or other actions from the fields in the farm map. This page is where the harvest logs were recorded and harvested versus sold calculations would be manually recorded.

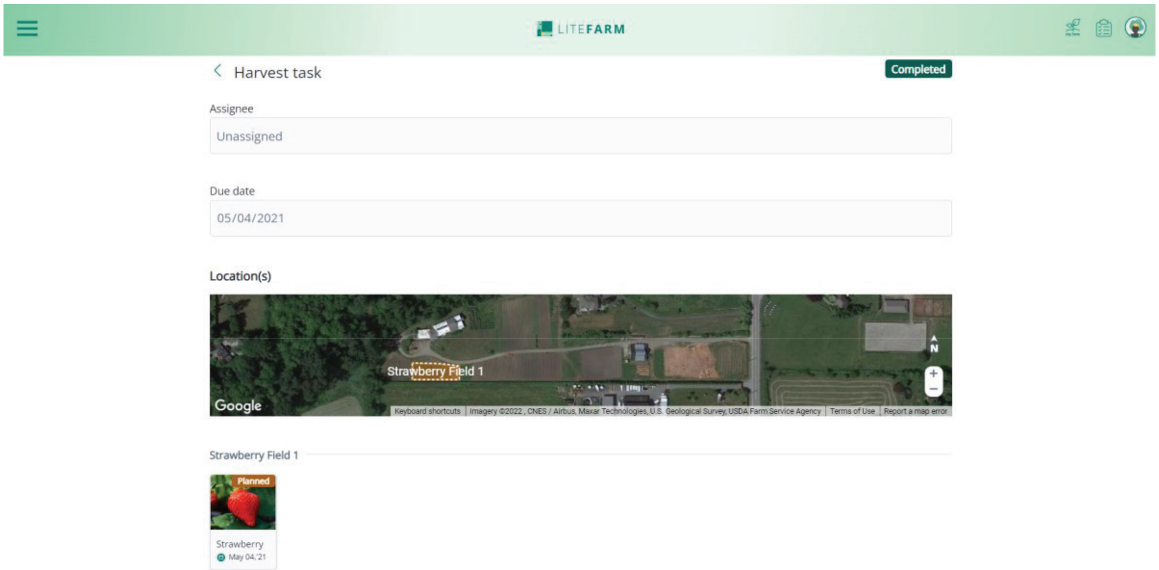

Figure 3: This page shows an overview for a given harvest log. Each log would be associated with a field and crop, allowing farmers to add a harvest use and quantity measurements.

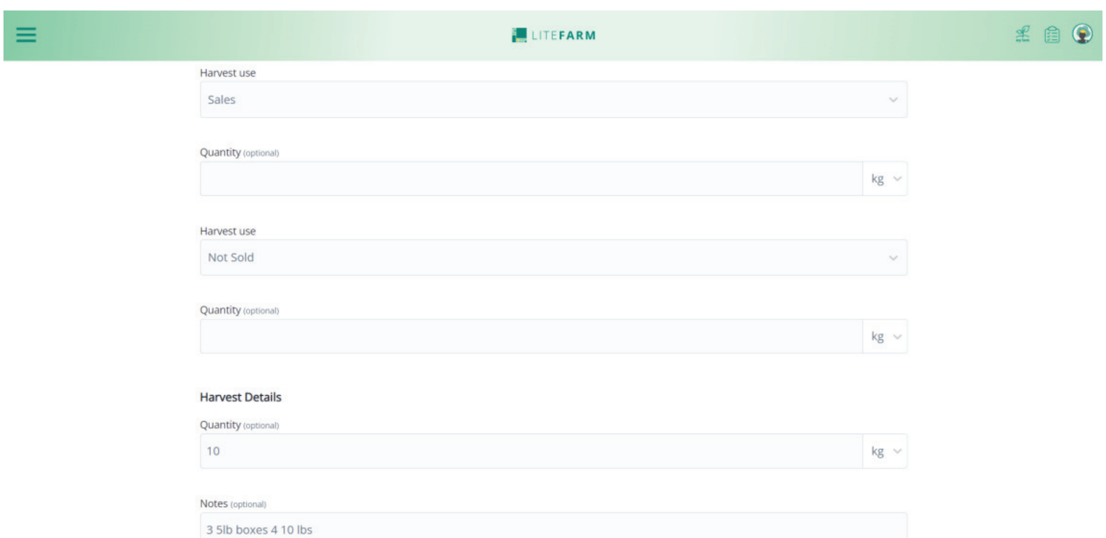

Figure 4: This page is related to Figure 3 as it is the bottom half of the harvest logs. This is where the use, quantity and other details are recorded.

Our method for estimating food loss saw farmers tracking their initial harvest and then inputting their sale records from that harvest. Once they had both numbers, they would take the difference between their harvest and their sales, and we quantified that number as the food loss. The harvest logs were the main feature used in the study; however, farmers were instructed on other features in the app that may enhance the overall experience. Creating fields using the map feature (Figure 5) and understanding overall environmental conditions with nutrient logs (Figure 6) were also used by farmers and could give the researchers insight into the overall effectiveness of LiteFarm as a management app. Creating mapped fields was required to input harvest logs, however, any other features were optional to the farmers.

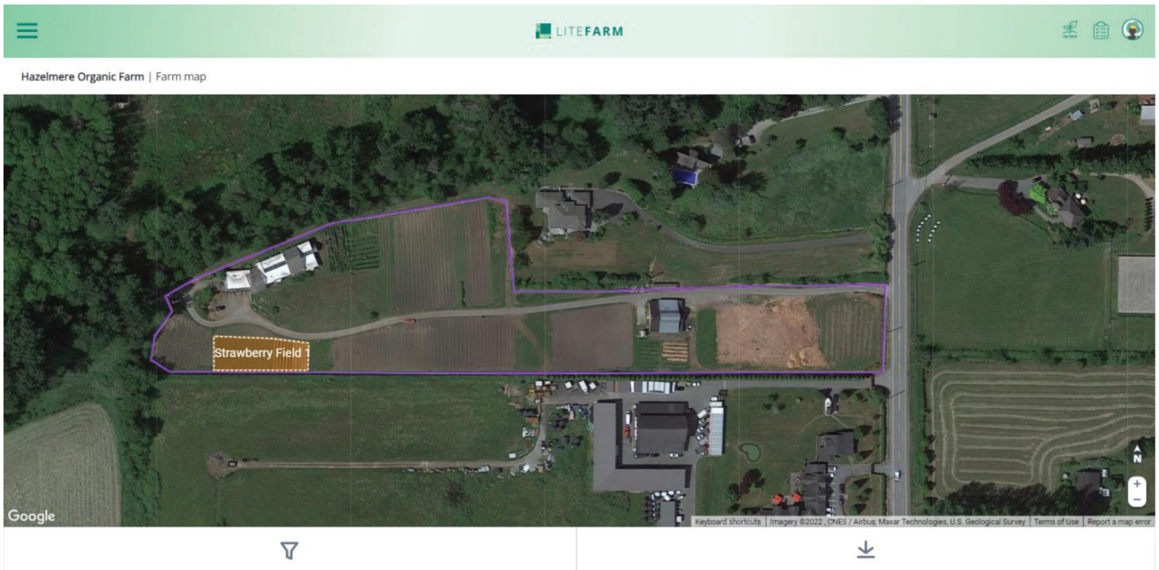

Figure 5: This LiteFarm page depicts the farm map, a feature where farmers add specific fields, draw property boundaries, and can judge spatial features.

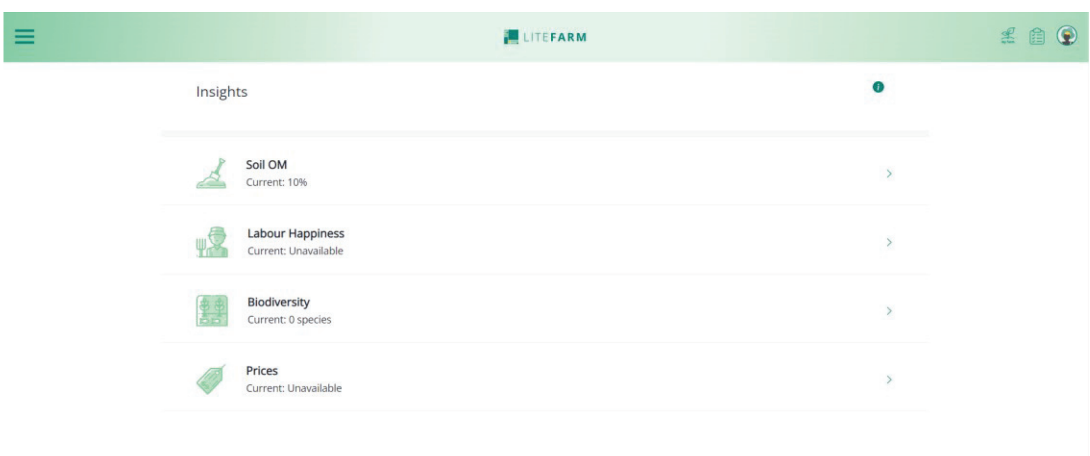

Figure 6: This page is the insights page, and it depicts features such as soil composition, labour happiness and financial records. This was an optional feature for participants.

Following the two trial periods for using LiteFarm, each participant was interviewed individually to collect qualitative data from their experience. The interview questions are included as an appendix. The interviews were either in-person or online according to public health restrictions and participant preference. On average, participants took approximately 30- 60 minutes to complete the post-trial interview. Interview participants were offered a $200 honorarium in exchange for their two months of testing the app. Each interview was transcribed using a software called Otter.ai and coded using the data analysis program NVivo.

The data analysis was done through NVivo using an inductive coding method. Inductive coding refers to qualitative data coding that first uses observations, in this case interviews, and developed themes from those observations (Chandra & Shang, 2019). Quotes associated with certain themes were counted and visuals created to emphasize aspects of food loss quantification and general app-based management on farms. For confidentiality, a pseudonym will be used for any direct quotes in the findings chapter.

3.3. Limitations

The limitations in this study include COVID-19, gaps in internet infrastructure, small sample size and experimental use of the LiteFarm app.

The COVID-19 pandemic brought unprecedented changes to the agricultural industry in itself, even more so when it came to implementing this research. Pandemic restrictions were not conducive to in-depth learning and created barriers in recruiting and establishing relationships with the participants. The COVID-19 pandemic also forced many farmers into financial crisis with supply chains severely constrained, this left many potential participants as well as current participants pressed for time and under undue stress.

Combined with the stress of COVID-19, four out of the seven farmers who participated had never used a digital agriculture app and had sporadic internet access. In the farm areas where the internet was sporadic, this made online training and general app usage difficult. Participants in north Surrey had better internet access and had more exposure to technology making their experience more streamlined. Under the COVID-19 pandemic conditions, the gaps in internet connectivity create inequitable results for using DAT.

An additional limitation was the small sample size of this study (n=7). This small sample size was helpful as the study required the researchers to be on stand-by to address the specific concerns of each participant, however it is not large enough to draw general conclusions from the results.

It is important to note that LiteFarm was not designed by UBC as an app for food loss quantification and this study looked to experimentally use an app for this unintended purpose. LiteFarm was designed by UBC as an environmentally oriented farm management app. The idea to use this app for food loss quantification was not initially seen by the developers and several customized settings had to be used for this study. There is no explicit "loss" category in the app, the food loss was calculated through a difference in harvest log inputs which are not tracked in the app but had to be manually recorded. This unintended use of LiteFarm may provide feedback for future updates of LiteFarm or new apps.

Having framed the study in terms of its research context, its methodology, and its limitations, the following chapter (Chapter 4) contains the findings of the study and discussion around the findings.

Chapter 4. Findings

The interview results that were compiled and analyzed provide a producer level perspective on food loss management with a digital agriculture app. The findings for this study have been categorized into themes resulting from the farmer's feedback and the qualitative coding in NVivo. Information about the participants can be found in (Table 1).

Table 1: Participant Information Table (pseudonym)

Farmer Name	Demographic	Mode of Farming	Size of Farm	Type of Crops
Robert	White	Organic	Medium 4 acre	Fruit and Vegetables (Wide Variety including Herbs)
Susan	South Asian	Organic	Small-Medium 2 acre	Fruit and Vegetables (Main Crop is Strawberries)
George	East Indian	Conventional	Large 10 acre	Blueberries
John	White	Conventional/Mixed Use*	Medium 5 acre	Fruits (Winery)
Jack	White	Conventional/Mixed Use*	Small 1 acre	Fruits and Vegetables (Wide Variety for Salad Boxes)
Karen	White	Conventional/Mixed Use*	Medium 5 acre	Fruits (Winery)
Jennifer	White	Conventional	Medium 5 acre	Fruits and Vegetables (Main Crop is Pumpkins)

*Mixed use refers to harvests that are used for multiple purposes for example apples that may be split and half of it is used for jam, the other half fermented for cider and the cores ground down and used in fertilizer

4.1. Overall Potential for Utilizing DAT as a Food Loss Quantification Tool

The main research question for this study hypothesized whether the app LiteFarm could be utilized to support better food loss quantification for farmers. After seven farmers tested LiteFarm, the general consensus was that LiteFarm's method to log their yield and sales and therefore measured loss was not more accurate than previous measurement techniques (e.g., paper documentation) and did not promote any behavioural change with regards to food loss quantification. All farmers specified that they did not formally and methodically measure food loss prior to this study. Jack, who is a small-scale, conventional/mixed use fruit, and vegetable farmer, had overall success utilizing the app for farm management purposes, however he only saw a vague connection to food loss quantification. Jack grows most of his crops in an open field, and he also has raised beds with a variety of crops including kiwis, pumpkins, peppers, and hops. When Jack was asked about using the app for food loss quantification, he noted:

> *"I never thought of it [LiteFarm] as a food loss app, maybe indirectly but not in a direct manner. It would have required more thought on my part to really find out what changes I would have to make" (Jack).*

LiteFarm provided farmers with the opportunity to track post-harvest food loss with the original intention being that digitized quantitative data may help provide a better understanding of both the environmental and economic impacts from food loss. Most farmers perceive their unharvested yield as small, however Johnson et al. (2018) highlights that these could be underestimates of the true loss, as their study estimates 5.9 billion kilograms of food is left unharvested in the US each year. While many farmers may oppose adjustments to their operation for a perceived loss, trying to uncover the true extent food loss may support behavioural changes to reduce environmental impact and increase economic returns. While some farmers may find manual entry on digital interface challenging, other farmers were excited about the convenience of using the app on their computer or phones:

> *"The idea of an app that can allow you to just enter activities on your phone is a great idea for tracking food loss especially in the organic sector, I think in general any technology that can help people save time is good" (Robert)*

“I think this technology on your phone can assist people with food loss measurement, it will be easy since we are on our phones a lot” (Jack)

While LiteFarm did not support food loss quantification for most of the farmers, DAT that can measure and track food loss can be attractive to farmers if it is convenience.

4.2. Barriers for Food Loss Quantification using Digital Agriculture Technology

4.2.1. Challenges with the Definition of Food Loss and Informal Approach

The farmers in this study identified food loss as produce that is unusable in their agricultural operation, which is very different from common definitions used in the FLW and agricultural literature (Chaboud & Daviron, 2017). This study’s participants saw food loss as a rare occurrence, because if produce was not sold it could be stored in freezers, tilled back into the soil, processed into a different product, eaten by livestock, consumed by the farmer themselves or even gifted to alternative food programs. Their perspective echoed the findings by Soma et al., (2021) which found that academic definitions of “food loss” did not always mesh with farmers’ view. The outlets to absorb “food loss” are deemed to be numerous and therefore many participants saw minimal utility in measuring “food loss”.

Food loss could have been better defined as potential economic losses or identified as impacting natural resource use. This will add different incentives to recording and help farmers see value in their time commitment. Identifying a clear definition for food loss and educating farmers on the added benefits of accurate food loss quantification could provide a better contrast between informal/sporadic food loss quantification and a more routine/organized approach via LiteFarm. During the interviews, several farmers noted their informal approach to food loss measurement prior to using the app:

“We [Farmers] know there are statistics out there and this [LiteFarm] could be quite practical and provide a proactive approach, right now it just happens in our brains” (Jack)

"Right now, it's all chicken scratch on my notes app, this [LiteFarm] could help out with a lot of that record keeping" (Robert)

Even though several farmers acknowledged the potential benefits to formalizing food loss quantification through a digital tool like LiteFarm, using the app for food loss quantification did not resonate for most of the farmers given this discrepancy around food loss definitions.

4.2.2. Time and Resource Scarcity

All seven participating farmers in this study quoted time scarcity as a strong barrier to using LiteFarm for food loss quantification. While each farmer managed their operation with a different style or personal philosophy, the reality is that farming is a demanding career. Farmers must grow their produce while also managing their relationships with processors, distributors, and retailers. When asked about measuring losses, several farmers had the same response, "No time". There are barely enough hours in a day for farmers to accomplish their daily tasks and asking them to carve out additional time for record keeping that is "theoretically beneficial" is difficult. LiteFarm as a tool offered a manual entry program to help accurately track food loss. Farmer such as Robert mentioned the time required to input the data:

"The manual entry was cumbersome, if the software had an automated feature or predictive features it might help incentivize farmers to use it" (Robert)

Manual entry app do not save time when quantifying food loss and can be a huge barrier for farmers thinking to adopt this type of farm management app. Whether LiteFarm was more accurate or not was not the issue as record keeping could not be prioritized over essential farming activities. Automation for data inputs becomes a very important incentive for farmers as it could solve this barrier for manual entry software. The idea around automation is that it only requires an initial set up and then it accomplishes tasks without continuous farmer input. There was a consensus among all seven farmers that an automated software would provide more value than LiteFarm in its current state, however, the specific features and what an automated software/app that can measure the losses at a farm entails would require further study.

Farmers also highlighted the complex timeframes of when agricultural planning takes place. A farmer's busiest time is during the spring and summer when there are physical field work tasks, LiteFarm is an app that requires constant inputs to remain accurate and valuable. Jack explains:

> *"Most planning happens in November, December, and January, this is when farmers would have time to sit down with a computer and plan or sift through records. If LiteFarm had an automated feature or a way to import sales records or harvest log notes it may become more valuable in those planning months" (Jack)*

If LiteFarm did not require constant action in the busy summer months, it may garner more interest from farmers that would like to study their stats in their quieter seasons. While our study anticipated the best results being in the summer months with real time data, Jack suggests that there would be more time to evaluate the data from LiteFarm during off-season time when farmers have the ability to reflect and plan.

4.2.3. Not a "One Size Fits All" Solution

Farming in Metro Vancouver is diverse and requires specific operational conditions to maintain a successful agricultural operation. This study looked at seven fruit and vegetable farmers, however, each farmer grew, organized, and sold their products differently. Given this diverse farming context, a broad approach app for food loss can be challenging to successfully implement. Two farmers in this study, Robert, and Susan, are both organic farmers in Metro Vancouver and apply for the same organics license with the same requirements. Robert grows fruits and vegetables on a four-acre property, some of these vegetables are exposed in open fields while others are protected in greenhouses. Susan grows her fruits and vegetables on a two-acre property with all of her fields being completely exposed. Even though both farmers are organic certified and mostly grow on open fields, their operational styles require different management techniques. Susan prefers to have her crops matched to purchase orders as soon as possible while Robert likes to assess his fields and make pre planting estimates. LiteFarm offers a generalized method for farm management, however, each farmer experienced the app differently, even when seemingly attempting to input similar information. Robert noted the issue with a one size fits all approach in digital agriculture:

“The app [LiteFarm] is one size fits all. It’s tricky to come up with […] it’s the nature of how people do things, changing the app would make it helpful for me but probably only me” (Robert)

John, a medium scale, conventional/mixed use winery farmer, provides a similar view on the need to be context specific:

“The app [LiteFarm] is useful but it comes down to the individual grower, some growers are strictly focused on increasing yields […] others may see value in the protecting their land and the environment, it depends on what values and style they use and maybe LiteFarm needs to have customizable options” (John)

One of the most frequent suggestions for the LiteFarm app was including customizable features like adding preferences or additional categories for record keeping. Those customizable features speak to the fact that farmers need specific help with their operations based on specific crops, activities, or the scale of the farm. This study found that the specific techniques used on a farm are not necessarily supported through generalized, broad scale software tools. Feedback from 3 out of the 7 participants expressed that LiteFarm’s lack of space to include qualitative reasons for food loss made it less effective to follow up on the reasons for food loss. Participants expressed a desire to record why a given quantity of food was lost so that they could brainstorm approaches to reduce or prevent that loss in the future. Jack specifically asked:

“A huge piece is the ‘why’, why does this food loss happen, it’s easy enough to record it but farmers need more information to address it. There needs to be an increased incentive besides for our own personal curiosity” (Jack).

Jack brings up that LiteFarm’s food loss quantification method did not include both quantitative and qualitative data to allow for a full picture of the agricultural operation. Currently, the farmers are not directly connecting food loss quantification with actionable food loss prevention and reduction methods.

If a farmer is not previously quantifying their food loss, it can be an added burden to measure and add a new daily activity. George is a blueberry farmer who sends all of their produce directly to a cannery following a harvest. The only method for food loss quantification would be picking up berries that have fallen off the bush and not retrieved for shipping to the cannery. The LiteFarm method for food loss quantification using manual inputs was not feasible as George estimates they ship roughly 5000 pounds of blueberries to the cannery per day. The only feasible method for food loss quantification would be an automated system (e.g., remote sensing) as you cannot hire people to pick thousands of blueberries off the ground. In contrast to George's case, Robert can use the LiteFarm method for food loss quantification as he sells his product to grocery stores and restaurants. This means that if he over produces a crop and cannot sell the whole harvest, he can manually track the loss easier. These results show that both the nature of farming techniques and the farm scale are key considerations to successful app-based management on a farm and more specifically food loss quantification using manual input DAT.

4.2.4. Educational and Technological Gaps

The use of digital apps generally benefits certain demographic, age ranges, and those with a certain level of technological experience. These gaps were identified by the participants and are seen as barriers to DAT adoption. Many farms may refuse to adopt DAT because they are family owned and have been operating for many generations without technological assistance. These farms may utilize specific growing techniques that hold unique value for the farmers:

> *"The number one barrier to digital agriculture adoption is because of succession related reasons, farmers learned from their father and grandfathers and may not so easily change with electronics and technology. They want to keep the farm running successfully while sticking with the family techniques. It will be the younger generation that changes" (Susan).*

Susan understands that farm operations want to maintain economic value without tarnishing a family reputation. Farms with these values may not adopt new technology that supports different agricultural techniques.

After DAT adoption, there were barriers that several participants including Robert, George, Jack, and Susan mentioned around "user friendliness". While LiteFarm offered a variety of interesting farm management options, some farmers found this to be overwhelming and diminish LiteFarm's user friendliness:

> *"There were times that it had too many features, it just became overwhelming and not user friendly with lengthy drop-down menus" (Jack)*
>
> *"You [farmers] could not just use an app for your operation without integration, the idea has to be user friendly and complementary, otherwise there is just too many other things to focus on" (Susan)*

Jack and Susan shared that technologies should be "user friendly" to be successful for farmers. If LiteFarm cannot provide a user-friendly experience, it can be cumbersome to utilize the app for food loss quantification. While many of the participants were initially willing to attempt to use LiteFarm for food loss quantification, it became evident in their interviews that without in-depth training and more time to gain comfortability, app-based management to measure losses would not be a top priority for their agricultural operations.

There were additional barriers related to language, demographics, and age ranges. George explained that his farm hires family and new immigrants who are mostly Asian or east Asian. Since they generally communicate in their native language, this restricts the type of on-farm activities they can do. LiteFarm has only three language options English, Spanish or Portuguese. This could pose issues for internal farm communication if immigrant farm workers were expected to help with app inputs. Furthermore, George explains that many farm workers are older, as younger generations are pursuing jobs in other fields, and no longer working at the farm. The older generations of workers have an additional technological gap even if they are English, Spanish, or Portuguese speakers. The use of DAT means new training is required for workers who may not be comfortable with technology in general. A combination of language barriers and generational technology gaps creates added difficulty when adopting apps such as LiteFarm for food loss quantification.

4.2.5. Competing with Economic Priorities

Food loss reduction has a prominent economic benefit for farmers in that they can generate more profits without growing more food. However, this economic benefit is difficult to realize without better understanding of how much food intended for the market is wasted and could have been utilized. In terms of priorities, this study confirmed Benyam et al’s (2021) findings that economic concerns weigh heavily on a farmer’s decisions and that without a guaranteed return from quantifying food loss, it would be difficult to justify the time commitment towards training and accomplishing this task. Farmers may also struggle with “temporal discounting” (Critchfeld & Kollins, 2001) as time scales for individual economic priorities do not align with broad environmental priorities. Many of the environmentally friendly actions do not show tangible results within short time frames. For example, land degradation or soil nutrient recovery happens over many years or decades which means mitigation measures will not show immediate results. This tension between economic and environmental priorities also relates to time and resource scarcity as farmers may elect to use their time differently for which tangible economic returns can be realized immediately.

Food loss costs Canadian farmers 2.88 billion dollars annually which means that there is an economic incentive for reduction (Nikkel et al., 2019). The participants in this study regularly pointed out that when losses occur, it was often due to factors beyond their control, such as competing with cheaper imports:

> *“Using LiteFarm, food may be described as lost because it was not sold. The reason could be because it was priced out by imported food that can sell at half the price of local food…” (John).*

John’s perspective also reflects the feeling of helplessness and the futility of measuring losses when there seems to be no alternative. This sentiment confirms the perspectives of other farmers around the inevitability of some amounts of food losses. However, it is important to note that by quantifying food losses accurately farmers may find methods for increasing their economic gains. Johnson et al (2018) concluded estimates of roughly 5.9 billion kilograms of marketable, unharvested food is left on fields annually in the US. If farmers adopted more accurate food loss quantification methods and had access to appropriate alternative markets, the current food loss situation could turn from an economic loss and a sense of hopelessness to an economic opportunity.

4.3. Opportunities for Food Loss Quantification using Digital Agriculture Technology

4.3.1. Pre-Harvest planning for Food Loss Prevention

One unexpected result that came from using LiteFarm was how some of the farmers used the app for pre-harvest planning which in theory could potentially help with preventing food loss. Although pre-harvest planning does not address the gap for accurately quantifying food loss, farmers identified LiteFarm as an efficient way to predict future harvests using their experience and the app's field mapping software.

> *"I would not use LiteFarm to track my food loss however I would more so use LiteFarm to maximize and more efficiently utilize land use which could indirectly prevent future food loss" (Jack).*

The land use and increased planning ability from LiteFarm was praised by three out of the seven participating farmers. In their view, LiteFarm has the potential to reduce food loss in the future through better pre-harvest planning. It is important to consider that the potential to maximize food production may result in more food losses if not managed properly. Benyam et al (2021) agrees that some DAT utilized to increase food production may lead to increased food losses if there were issues further down the FSC such as retail space constraints or insufficient distribution capacity.

John praised LiteFarm for its ability to highlight inefficiencies on his farm and although this did not relate to food loss quantification it did indirectly help him reduce his food loss. John described:

> *"LiteFarm helped us maximize our yield, by this I mean our labour could be optimized for a given period. If I know my apples need pruning now and will be harvested in a week, I can schedule my workers accordingly and avoid over scheduling or under scheduling which may lead to loss or high production costs. On my end this means I can pick more apples with my production cost savings. I will indirectly lose less. For me it's about the costs". (John)*

With John seeing LiteFarm's economic incentives through better labour scheduling and increased overall harvests, John was more willing to devote time and energy to the planning or record keeping processes. Several farmers including Susan, Jack and Robert also mentioned land degradation concerns and identified positive unintended outcomes from using LiteFarm's planning capabilities. Jack specifically mentioned using LiteFarm for "cover crop planning" which allowed him to map out cover crops, create rough timelines for nutrient uptake periods and plant during optimal times.

An additional pre harvest planning aspect that was suggested by Susan pertains to facilitating communication between food supply chain actors. LiteFarm has the potential to host a type of communication network that would support pre harvest planning with transparent, streamlined food supply chain actions. Susan describes this example here:

> *"I spend a lot of time on managing orders, talking on the phone with grocery stores, distributors, restaurants, and they all have different contacts and different orders on different days. It becomes a lot of switching from different communication platforms, if you had something that put those together or at least reminded me who I need to talk to and why, that would be helpful". (Susan).*

Susan identifies this opportunity for food supply chain actors to communicate in an organized manner. If this network was established, certain actors such as retailers and restaurants could easily identify existing food or upcoming harvests from their producers and make changes to their consumer offerings. If retailers are utilizing already harvested food or ordering planned harvests this makes producers less anxious about if they can sell their product and provides an incentive for pre harvest planning if orders are secured in advance. These quick changes could indirectly support food loss reduction and prevention if retailers could make use of existing product and support more accurately planned harvests.

4.3.2. Increasing Awareness of Environmental Issues

Farmers in Metro Vancouver practice numerous environmentally friendly farming styles and philosophies including organic farming, vertical farming, permaculture, and urban agriculture (Metro Vancouver, 2011). Environmental priorities may play a larger role as agriculture moves toward a more climate uncertain future (IPCC, 2022). Climate change will lead to increased land degradation and create significant economic losses, amplifying the need to protect arable land and reduce food loss (IPCC, 2022). However, conventional farming practices that anchor many of Metro Vancouver's large scale food producers may not easily shift towards more environmentally friendly practices. DAT that highlights these environmental concerns may provide a mechanism for environmental awareness even with conventional operations. For example, as one the large-scale farmer in this study, George described their emerging awareness about the issue of food loss and its environmental impact:

> *"I don't know if this [re: LiteFarm's food loss measurement] ties into the environmentally friendly part of farming but the loss of product to us is huge […] I never really considered climate change as a factor in our personal operation and knowing the connection to our harvest will be important moving forward" (George).*

While George had no intention of neglecting environmental considerations with his operation, it is apparent that the economic aspect weighs heavily on his mind. When George realized the connection between climate change and his losses, he noted how this information will impact how he moves forward. Understanding that education can provide new positive outlooks for these farmers is important. To contrast this, organic farmers like Susan, who regularly uses organic fertilizers, crop rotation for nutrient balancing and organic pest control substances, see environmental values differently:

> *"For organic farmers, it [environmental value] is infused in us […] we have that advantage, and we try to educate when we can" (Susan).*

While being an organic farmer gives Susan an advantage when faced with environmental issues; conventional farmers such as George may also have an opportunity to increase their environmental awareness while using DAT.

Chapter 5. Discussion & Recommendations

Our results on the use of the LiteFarm app for food loss quantification were mixed, with some farmers enjoying their experience and others feeling overwhelmed. It became clear that LiteFarm is a great tool for planning, but in this study, we found that it was challenging for farmers to use the app during the busy growing season. The barriers for using LiteFarm as a food loss quantification DAT, and its unintended use as a pre-harvest planning tool are highlighted and compared to previously published studies.

Table 2: Findings Summary Table

Theme	Sub-Themes	Summarized Findings
Barriers to Food Loss Quantification	Time and Resource Scarcity Not a "One Size Fits All" Solution Educational & Technological Gap Competing with Economic Priorities	Farmers face time scarcity and food loss quantification is not incentivized. DAT may require specific features related to a given farmer to be effective for food loss quantification Farming styles and successional techniques hinder digital agriculture adoption and usage. Age, Language, technological capabilities, and Demographic are barriers to DAT adoption and a more equitable design approach may improve usability Economic priorities will outcompete environmental or social benefits from DAT.
Opportunities for Food Loss Quantification using Digital Agriculture Technology	Pre-harvest planning for Food Loss Prevention Increased Awareness of Environmental Issues	Food Loss quantification using DAT can enhance a farmer's understanding of environmental issues related to food loss Pre-harvest planning can support future food loss prevention with better organization and more accurate future harvest predictions
Recommendations for Food Loss Quantification with	Flexible Inputs Integrate Communication	Use of Qualitative data for food loss metrics to add information about how a given loss can be addressed.

Digital Agriculture Technologies	Tools to Allow for Supply Chain Transparency Create Automated Features to Mitigate Time and Resource Scarcity Improve Language Options and Inclusivity	Collaboration between app developers and farmers for specific features Integrating communication tools for all actors working on a given order in the food supply chain Adding more emphasis on planning features and automated calculations rather than real-time tracking could increase LiteFarm's attractiveness to farmers Adding more language options and collaborative design elements to encourage inclusivity

5.1. Barriers to Food Loss Quantification

This study found several barriers for food loss quantification using DAT including time and resource scarcity, generalized technology designs, educational gaps, technological gaps and competing economic priorities. One initial barrier to participation in food loss quantification is that farmers' approach and perspectives around food loss differs from typical academic definitions. The FAO (2019) defines food loss as food that is lost in the production, post-harvest, and processing stages up to but not including retail. However, this study found that farmers were hesitant to define unsold foods as "food loss" since alternative options exist such as tilling food back into the soil, processing them into non-perishables or donating food to alternative markets. There is also an expectation by the farmers that there will always be losses, which added to the hesitancy of quantifying the inevitable. However, Johnson et al (2018) found that many food loss statistics were underestimated, potentially due to inconsistent definitions for food loss or confusion related to alternative uses. This study and other food loss quantification studies (Johnson et al., 2018; Delgado et al., 2017; Sheahan & Barrett, 2017; Hartikainen et al., 2018) stress the importance of measuring food loss even though farmers may express concerns and not see immediate benefits. Inconsistent food loss definitions also brings up concerns related to cognitive dissonance. Markowitz et al. (2014) describes the challenges with climate change communication when certain mitigation measures may impact an individual's livelihood. In the case of food loss, most farmers understand the environmental impacts of postharvest loss (Soma et al.,2021), however their personal livelihoods and financial situations make addressing food loss difficult. As such, farmers may elect to ignore food loss quantification all together to avoid internal tension and guilt for their potentially less environmentally friendly approach. Accurate food loss quantification will require consistency in its method and considerations for the complexity of behaviours and different contexts seen in the agricultural field.

There are barriers to LiteFarm's adoption that were inherent to certain farms given their specific farming routines. For farmers with different types of crops, committing several hours of data input for every harvest is difficult. Johnson et al (2018) and Alexander et al (2017) both agree that time scarcity is a major barrier farmers face regarding food loss quantification and adopting new DAT. Training, inputs and equipment maintenance all contribute to labour costs and time spent on daily operations which, without guaranteed returns, creates a tension against economic priorities (Benyam et al., 2021).

DAT adoption has different challenges as many farm technologies have been designed as a "one size fits all" solution not acknowledging the educational and technological gaps in diverse farming contexts. For example, rural or small scale farmers may face barriers such as gaps in internet infrastructure and financial constraints that are not present in large-scale, urban farming operations (Weersink et al., 2021). In this study, farmers experienced internet connectivity issues in some of the rural areas of Metro Vancouver. This hindered both online training opportunities as well as daily inputs for LiteFarm. Farmers in these rural areas generally had a small living establishment or lived in housing away from their agricultural operation resulting in a lack of established internet infrastructure for themselves. Furthermore, rural farming towns have expressed that internet infrastructure may not be a top priority compared to healthcare or telecommunications for their town or municipality (Weersink et al., 2021). Bronson (2019) found that when rural, small-scale farmers were asked about benefits from DAT their responses expressed historic concerns that DAT would only benefit industrialized operations and already powerful food systems actors. Without guaranteed returns for individual returns, farmers would be less willing to support building new infrastructure for data-based DAT (Bronson, 2019). Similarly, small, polyculture farmers who depend on diverse agricultural techniques see less benefits from DAT compared to larger, conventional or commodity type farmers (Bronson & Knezevic, 2019). DAT is programmed to provide large data sets on individual crop which could be more influential for monoculture or commodity farmers that focus on a few desirable crops (Bronson & Knezevic, 2019). Smaller, polyculture farmers rely on several different crops for one order, maybe in the form of salad boxes or CSA type programs. As seen in this study, farmers were able to use LiteFarm's flexibility to their benefit, however, most DAT focusses on large scale commodity crops with large data sets which may not be useful for a general group of small scale polyculture farmers (Bronson & Knezevic, 2019). Furthermore, if small scale, rural farmers become dependent on DAT it may expose them to financial volatility related to equipment maintenance (Rotz et al., 2019). Once farmers are accustomed to technology or have incurred debt to acquire the technology it can financially lock in those farmers (Rotz et al., 2019). Fortunately, LiteFarm is open source and free which could pave the way for other open source technology that allows for creativity and technological advancement without incurring debt for high end equipment. However, LiteFarm exposed language inclusivity issues that may arise with DAT adoption. Many farms may employ multicultural labour or operate under agricultural standards from around the world. As Soma and Nuckchady (2021) describe equity for DAT is important for broad adoption and features such as different languages, universal visuals and flexible qualitative inputs are important in the agricultural field.

For some farmers, the lack of empirical evidence surrounding DAT is a considerable barrier for adoption as it creates a tension with their economic interests. Specifically for large scale farms, any technology that does not have proven success from a trusted source and cannot guarantee economic returns will not be implemented (Shepherd et al., 2020). Moreover, these economic priorities will often take precedent over food loss quantification and associated environmental or social factors (Benyam et al., 2021). The use of DAT for the purpose of food loss quantification highlights competing priorities; Benyam et al (2021) describes how farmers may see benefits from DAT adoption for the purpose of FLW prevention or reduction, however, the risk of failure and the time needed to use new technology may disincentivize new adopters (Benyam et al., 2021). Another concern related to DAT adoption relates to the social aspects and concerns around data ownership. Soma and Nuckchady (2021) highlight farmers' concerns for data ownership and government/regulatory oversight. This relates intergovernmental data sharing which Soma and Nuckchady (2021) found to disturb farmers because they would not know who might be utilizing their data and why. These concerns were echoed in this study's recruitment phase. Several prospective farmers were unsure about participating in this study, and a few were willing to share that they did not want their food loss data shared with the government, the technology company, or any farmers in their community. These concerns stemmed from social ridicule they might face if their food loss data was not considered appropriate and this relates to the previously identified cognitive dissonance barrier discussed in this paper (Markowitz et al., 2014). If food loss data is considered inappropriate by government standards or the agricultural community, it could lead to social concerns in the food supply chain and in some cases significant financial losses. Farmers grapple with this idea about data privacy and their reputation in the community, therefore food loss quantification and DAT adoption may be completely ignored if it cannot guarantee individual privacy or gain collective approval.

5.2. Opportunities and Positive Unexpected Outcomes

Food system planning can be an indirect tool for food loss reduction and prevention through land use changes. This study highlighted that by utilizing digitized maps and agricultural experience, farmers were able to efficiently organize their land base and ultimately plan to produce more food in the future. As supported by Messner (2020), food loss prevention is more important in the food loss hierarchy, however, reduction is more commonly researched and practiced in our global food system. The literature on DAT identified how automated sensors can provide predictive land management tasks from current and past conditions (Nazirul et al., 2020) or utilizing farmer experience with technological support to maximize land use (Finger et al., 2019). LiteFarm has taken both predictive land management and input mapping to create a flexible crop planning experience for farmers. When LiteFarm was proposed to our participants as a way for food loss quantification, it was initially met with skepticism, however, when training for LiteFarm included mapping fields and tracking potential harvests, many farmers described this as a high value planning method. Mapping allowed farmers to dictate their own boundaries, use their knowledge to create a map of their farm, and draw practical conclusions from their experience.

While better land use may benefit society by slowing agricultural land expansion and mitigating land degradation (UNCCD, 2021), it may not support issues related to market volatility and weather risks that lead to overproduction. Soma et al (2021) highlights that farmers overproduce as a form of insurance related to market volatility, weather risks and contractual obligations. This overproduction may lead to increased land degradation and increased costs for the farm. Golan et al (2020) proposes an idea of optimal food loss where overproduced food is necessary to ease risks. LiteFarm and other DAT apps may allow farmers to utilize their current land base better and increase yields. However, without adequate markets or alternatives, increased food production may further exacerbate the situation.

Social factors may push farmers towards DAT adoption following initial uncertainty. George, a large-scale blueberry farm in this study initially saw no benefit from the LiteFarm app for his operation. However, he agreed to test the app after a reference from one of his colleagues. Farmers can be persuaded to adopt new techniques or technologies if there is a social precedent or reference from the community, Le Coent et al (2021) supports the point that farmers are influenced by social norms especially if their peers are voluntarily protecting an environmental or economic public good such as air quality, ground water quality or farmer's market infrastructure. In the case of DAT, farmers may choose to support new technology testing if other farmers agree on broad scale benefits such as efficient land use planning or other environmental benefits.

5.3. Recommendations

The following recommendations have been developed through consultation with the farmers identifying best practices from agricultural literature. The recommendations are geared towards improving future food loss quantification effort as well as feedback on how to improve apps like LiteFarm.

5.3.1. Flexible inputs

One barrier expressed by the participating farmers in this LiteFarm study was the lack of customizable features, this includes creating preferences, customizing drop down menus and an expanded labelling system. While this comment is specific to LiteFarm, it can be extrapolated to other potential food loss quantification software. Providing users with the ability to label their logs with notes can create a tailor-made feel which adds to an overall user-friendly experience. LiteFarm did possess several customizable features including "other" labels which are the bare minimum needed but not fully expansive. User friendly features require that DAT developers collaborate more with farmers and consider flexible inputs will create that user friendly experience from the start. Similar to flexible inputs, co-development was a suggestion made by Robert for meeting a farmer's specific needs, this could include specific user options such as farm type (conventional, organic), farm size, or farm partnerships (technology partnerships, government funding). Co-development would require a collaborative relationship between developers, researchers, and farmers; however, it was acknowledged that this process would be time intensive, costly, and complicated. However, a co-design process would help answer the question of " who is this technology serving" as the academic/farmer relationship should not be too heavily weighted towards the interest of academics. Farmers may respond more positively to an app that focusses on their needs such as practical methods for food loss reduction and prevention instead of measuring their inevitable food losses. If an app can be customized to fit a farmer's unique experience and practical needs it may provide value in terms of general farm management. This framing and co-design will become important for supporting for DAT adoption. Farmers may be more willing to utilize DAT if it is framed as a food loss reduction and prevention tool versus a food loss quantification tool because the former fits their practical needs.

5.3.2. Integrate Communication Tools to Allow for Supply Chain Transparency

Communication on a farm is essential for a successful operation and for food loss prevention and reduction. LiteFarm provided a new potential framework for internal and external communication capabilities. Currently many farmers have several applications to manage their finances, seed records and contracts but the prospect of having an "all in one" management app such as LiteFarm was novel and valuable. Using LiteFarm for food loss records as well as communication with farm workers could provide time savings and financial savings with potential increased efficiency. Our recommendation is that apps such as LiteFarm increased their communication capabilities to include instant messaging or a collaborative calendar feature to update information for more actors in the FSC. This could include retailers, processors, alternative markets, or other farmers who can check a status on their own computer instead of trying to contact farmers who are constantly busy. Furthermore, increasing transparency and communication with a collaborative software could become an option for reducing or preventing food loss. For example, FSC actors can make decisions according to current and future food availability after finding information in an app like LiteFarm.

5.3.3. Create Automated Features to Mitigate Time and Resource Scarcity Constraints

The largest barrier to adopting DAT such as LiteFarm is time allocation and an important aspect to addressing this is automation. LiteFarm required manual inputs which had the potential to track food loss with greater accuracy than written notes, visual estimates or excel sheets. However, the time required to input these statistics was a large barrier for this study's participating farmers. Our recommendation is the inclusion of automated features in an app like LiteFarm. These features could include compatibility with automated sensors or predictive software. There are many digital agriculture technologies with sensors including drones and soil monitors (Klerkx & Rose, 2020). Therefore, the potential for those technologies to be integrated into a farm management app is possible. The second automated feature could include predictive technology. This option combines farmer experience with the fast-processing power of computers to create future projections for agricultural processes. This could be used for anything from water usage to food loss quantification and it would only require an initial set up and minimal future inputs. The important consideration for predictive technology is that farmers can provide feedback to the computer and adjust settings to accommodate their operation. In the end farmers only have so much time to spare and if there is a technology that they can trust, that will also save them time it could be a huge advantage for their operation and a step towards positive digital agriculture adoption.

5.3.4. Improve Language Options and Inclusivity

Language barriers are a prevalent concern with DAT and its adoption by farmers. As identified in the findings, the demographic for farmers and their workers is diverse including multiple languages and cultural norms. DAT is traditionally designed for English speaking farmers and in LiteFarm there were only three options for languages, English, Spanish or Portuguese. Especially in North America where a single farm may include several different language speakers, DAT should look at incorporating more language inclusivity into its designs. This may come in the form of direct translation or universal visuals that are more accommodating to different cultures and languages.

Additionally, the methods for training and instruction on DAT should be inclusive for a variety of demographics,. Soma and Nuckchady (2021) discuss their concerns for including proper engagement with interest groups before attempting to implement new DAT training. Researchers and technology developers must understand a farmer's personal priorities or given values to create an equitable and collaborative space.

Inclusive features should also consider internet existing infrastructure gaps and offering the technology in an offline mode. Farmers may not have the technological abilities or internet infrastructure to set up and navigate online technology 24/7, however, developing technology that can be used offline on the field can improve inclusivity and accessibility for DAT usage. Farmers can utilize offline technology with their workers and avoid the challenges in an online interface. Furthermore, if their internet infrastructure will not support real time online software, an offline mode allows farmers to still use their technology and upload the data when the opportunity is present. Developing offline settings can also support privacy and individualized approaches to data collection, as farmers will have the opportunity to collect, sort, and filter their data before releasing it online.

Chapter 6. Conclusion

The use of DAT has the potential to create positive contributions to food loss measurement, prevention, and reduction. This study highlighted some of the potential opportunities from the use of digital agriculture through the use of the farm management app LiteFarm. This study started with two main objectives, 1) to assess the DAT's potential as a tool for food loss quantification and 2) to identify the opportunities and barriers for farmers adopting and using DAT as a tool for food loss quantification. The findings demonstrate that although DAT has the potential as a tool for better pre-harvest farm planning, it did not resonate with most of the farmers as a tool for food loss quantification. This is primarily because farms operate on different scales and utilize diverse agricultural techniques which were not captured by a "one size fits all" technology such as LiteFarm. As food loss often occurs due to factors beyond the farmers' control, (Soma et al., 2021) several farmers felt that measuring losses felt futile. This study found that economic priorities will outweigh environmental priorities, agreeing with Benyam et al. (2021) who also found this as a barrier to DAT adoption because farmers were not guaranteed economic returns for the given time investment. DAT was also shown to affect farmers differently depending on agricultural worldview, farm size and crop type; this is echoed by Bronson & Knezevic (2019) who discuss DAT bias towards large commodity farms versus small polyculture farms. Furthermore, Roe (2020) confirms that a successful measurement method or technology must recognize the complexity and nuances around the diversity of different farms. There will rarely be a standardized method or program for food loss quantification and DAT may just be a tool that is shaped with a given farmer's experience.

One unexpected aspect of the study is the potential for the app to improve land use management which may lead to decreasing land degradation, better labour planning and increased financial security for farmers. This is important considering the United Nations (UN) report that roughly 25 percent of the global land base is degraded by over usage and climate related impacts (UNCCD, 2021). While these outcomes do not directly address food loss quantification, it can potentially support efforts towards food loss prevention. Unintended findings about the potential for pre-harvest planning means that future follow up studies should consider exploring the food loss prevention and pre-harvest planning relationship. To conclude, while this study found that technology may offer opportunities for farmers, it is important to support deeper collaboration with farmers when designing new DAT to support food loss quantification. Initiatives such as co-creation and collaboration will help to improve user friendliness and prioritizing language inclusivity will better support the ability for diverse farmers/farm labourers to use the tools. Digital agricultural tools like LiteFarm can help support the broader goals of food loss prevention and potentially reduction, but the tool itself will not address the root cause of the food loss problem and deeper issues around time scarcity and lack of resources. Solving the food loss problem will require more equitable relationships between all actors in the global food system.

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Appendix

Post-LiteFarm Use Interview Questions

1. Can you share your role and why you decided to participate in this study?

2. Prior to using FarmLite app, have you ever used a farm management app or digital tool for your farm-related work?

    - If yes, what was it and what was it for?
    - If no, can you elaborate why?

3. What was your overall impression of the FarmLite app? Can you elaborate both on the positive and negative aspects of the app if there were any?

4. Was the training we provided sufficient? Do you have any feedback on how we could have better prepare you to use the app?

5. Prior to using FarmLite app and this study, did you measure the amount of post-harvest food loss/waste?

    - If so how? Did FarmLite make measuring post-harvest food loss and waste easier?
    - If not, why? Did FarmLite make measuring post-harvest food loss and waste easier?

6. What would be your recommendations for apps such as FarmLite?

7. Do you see a role for apps like FarmLite in contributing to better/more efficient/more environmentally friendly farming practices and better measurement?

8. What are some of the barriers for farmers to adopt this more widely?