CLIMATE CHANGE
ADAPTATION PROGRAM

State of Practices & Technologies Assessment for Managing Extreme Heat Impacts

Project Report

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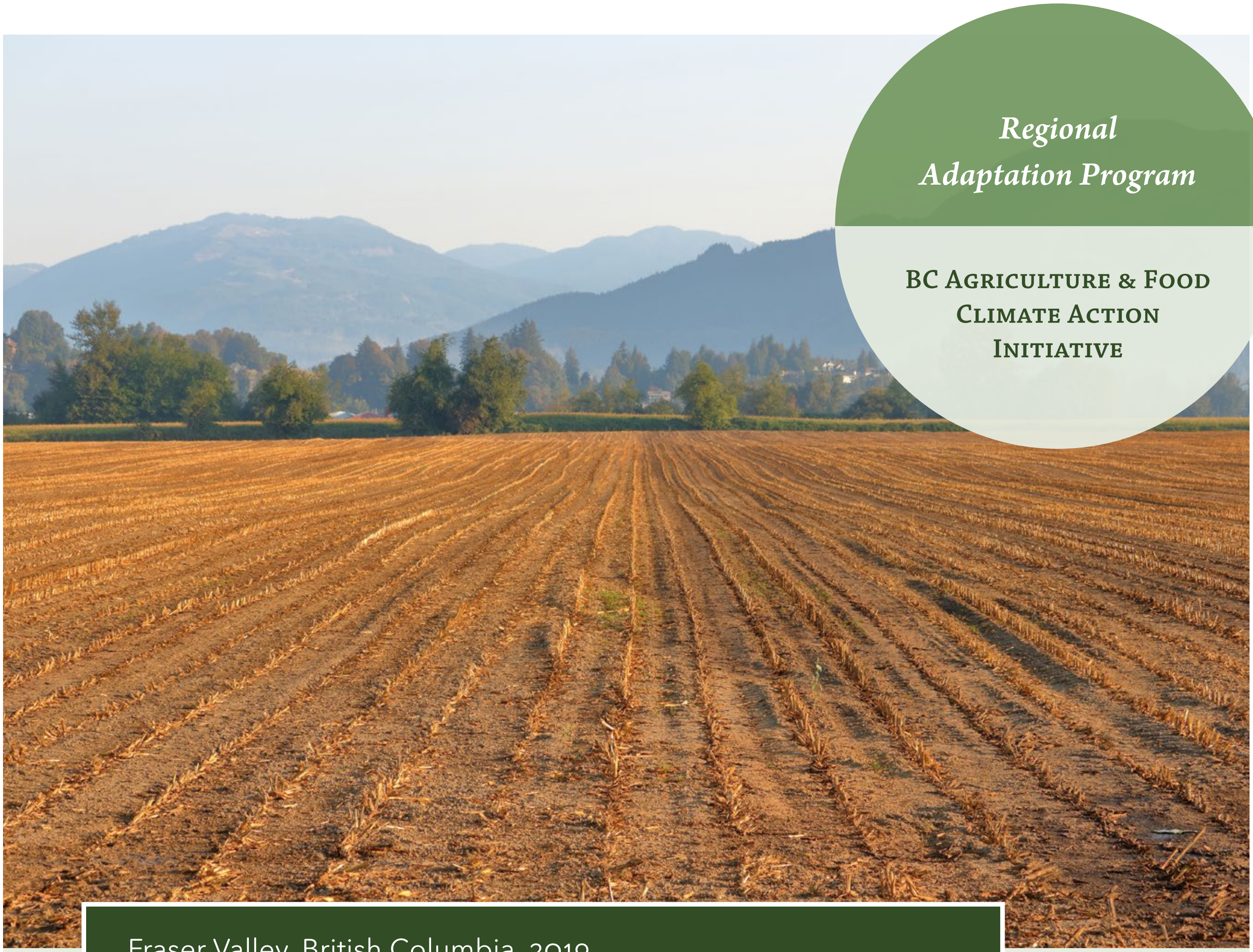

Regional
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BC Agriculture & Food
Climate Action
Initiative

Fraser Valley, British Columbia, 2019

State of Practices & Technologies Assessment for Managing Extreme Heat Impacts

Project Report

Fraser Valley — State of Practices & Technologies Assessment for Managing Extreme Heat Impacts: Project Report

Prepared by ***Upland Agricultural Consulting***,
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Disclaimer

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- BC Blueberry Council
- BC Dairy Association
- BC Poultry Association
- City of Abbotsford
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- District of Kent
- Fraser Valley Regional District
- BC Ministry of Agriculture
- BC Agriculture & Food Climate Action Initiative

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Table of Contents

Table of Tables

Table of Figures

Acronyms

AAFC	Agriculture and Agri-Food Canada
ABV	Australian Breeding Values
AGRI	BC Ministry of Agriculture
CAD	Canadian dollars
CFM	Cubic feet per minute
DMI	Dry Matter Intake
FLNRORD	BC Ministry of Forests, Lands, Natural Resource Operations & Rural Development
HVLS	High Velocity Low Speed fans
OMAFRA	Ontario Ministry of Agriculture, Food and Rural Affairs
PCIC	Pacific Climate Impacts Consortium
POC	Project Oversight Committee
RH	Relative Humidity
SWD	Spotted Wing Drosophila
THI	Temperature-humidity index
TNZ	Thermal Neutral Zone
VSD	Variable Speed Drives

Executive Summary

Introduction

As the climate changes, agricultural producers will need to be proactive in identifying and adopting adaptive practices and technologies. While average annual temperatures are expected to continue to rise in all seasons, extreme heat events are anticipated to occur with greater frequency and intensity during summer months, when both extreme daytime highs and warmer nighttime lows will occur[1].

The common heat management technologies and practices currently used by Fraser Valley producers may not meet cooling requirements of livestock and crops into the future. Depending on the scale of production, it may be possible for producers to absorb occasional negative impacts associated with extreme heat (e.g. losses to one flock cycle for poultry or impacts to berry or forage crop yield or quality). However, when losses become more frequent or are sustained over time, the threshold at which adoption of additional heat abatement practices and technologies is justified will be reached.

Fortunately, adoption of (suitable) technologies and management practices used in other jurisdictions with warmer climates may assist producers in managing the changing conditions. This report identifies and assesses these technologies and practices, with a specific focus on the poultry, dairy, and berry sectors, and their applicability to the Fraser Valley agricultural context. Some of the technologies and practices have already been adopted (on a limited scale) by Fraser Valley producers, but most are not widespread. Recommendations for additional research, analysis, and/or development of new informational resources are identified and summarized.

Methods

This report was informed by two phases of stakeholder consultation, a literature review, and a jurisdictional scan. The consultation included in-person and telephone interviews with 31 individuals, including producers, industry experts, government staff, and consultants. The literature review encompassed over 100 reports and articles, and the jurisdictional scan focused on regions with similar agricultural sectors already accustomed to more frequent high temperatures (e.g. Oregon, California, Georgia, Alabama, Texas, Florida, United Kingdom, France, and Australia).

Poultry Context and Recommendations

The Fraser Valley poultry producers consulted for this report raise layers, broilers, broiler breeders and turkeys and oversee operations of varying sizes within the supply management system. Specific heat management strategies differ depending on the size and type of the poultry operation. Broiler producers are large scale and are primarily using tunnel ventilation, often with cooling pads. Other types of operations (e.g. layer and turkey) are using cross-ventilation and/or mister systems. It is often the flock cycles of July, August and September that are most at risk of being negatively affected by high temperatures.

Many elements of poultry production – such as barn design, flock genetics and feed formulas – are highly technical and carefully managed by producers[2]. However, stakeholders mentioned that flock mortalities

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[1] Fraser Valley - BC Agriculture & Climate Change Regional Adaptation Strategies series. 2015. BC Climate Action Initiative.

[2] BC Ministry of Agriculture, 2016. Agricultural Building Ventilation Systems. Publication 306-412-1.

due to heat do occur from time to time in the Fraser Valley. As heat events become more extreme and more common, this may necessitate changes to flock management strategies and adoption of new technologies. However, each decision to incorporate new technologies is weighed from a cost-benefit perspective, pointing to the potential value of having more information readily available.

Lessons can be learned from poultry-producing areas that are already warmer than the Fraser Valley. Georgia, Ontario and the UK were the regions that frequently arose in the jurisdictional scan. The literature review and jurisdictional scan of technologies and management practices found that some Fraser Valley producers are already using effective cooling methods. However, there are additional opportunities for continued improvement in heat mitigation that may be effective.

Opportunities for further technology adoption by the Fraser Valley poultry industry include:

- Use of apps to measure the Temperature Humidity Index (THI): Apps are a quick source of feedback for producers to determine temperature and humidity conditions. The use of these apps is not widespread in the Fraser Valley poultry sector and they could be promoted as tools to help inform management actions.
- Exhaust Ventilation and Evaporative Cooling: It is likely that with projected increases in temperatures a broad range of poultry producers will adopt fully enclosed exhaust ventilation systems for increased cooling potential. Most new poultry operations in the Fraser Valley include tunnel ventilation with evaporative cooling systems (e.g. cooling pads or misters) to manage heat. Determining the suitability and cost-benefit of high-pressure misters versus cooling pads for various scales of poultry production and barn designs could help inform producers about cooling options.
- Ground Source Heat Pumps: This technology is beneficial for temperature control and reduces energy costs while addressing heating and cooling needs. However, it is a costly capital investment with a long payback period, and there are no examples of this technology to learn from in the Fraser Valley. As research into these systems continues around the world, more information may become available to Fraser Valley producers and equipment specialists to aid in determining applicability for the Fraser Valley.

Several opportunities exist to gather more information, undertake knowledge transfer and/or evaluate specific technologies for applicability to the poultry sector in the Fraser Valley. These include:

1. Clarify potential transferability, producer interest and current uptake of heat stress apps. If interest exists, conduct pilots/trials of available heat stress apps (e.g. Thermal Aid) to evaluate their applicability for the Fraser Valley poultry sector.

2. Develop fact sheets and/or case studies regarding:
    - Tunnel ventilation & cooling pads in a new poultry barn install
    - Tunnel ventilation retrofit into existing poultry barns
    - Comparison of evaporative cooling technologies (e.g. misting systems vs. cooling pads)
    - Ground source heat pump feasibility

    These materials would document existing installations and technology applications and include economic information.

3. Develop materials to establish a standard for design (to address the wide range of design variations and resulting quality/performance) and to outline effective operational strategies for improved

tunnel ventilation system performance[3]. These materials could consist of fact sheets, maintenance and monitoring checklists, or case studies. Training sessions could be offered for producers on how to effectively operate and maintain their existing systems.

4. Develop fact sheets or other informational materials on best practices for managing the potential negative impacts of increased humidity using high-pressure misting and cooling pads.

Dairy Context and Recommendations

The most common heat management practices/technologies being used by Fraser Valley dairy producers include natural ventilation (e.g. openings inside walls and end walls) with additional circulation (e.g. fans). A small number of producers are using of radiant barriers on the underside of barn roofs, and high-pressure evaporative cooling systems (e.g. misters). Most barns have automated climate control systems to turn air circulation systems on and off. Producers have noted some impacts of extreme heat already, but most feel that the heat events are not yet frequent enough to warrant substantial investments in additional cooling technologies or management practices.

Opportunities for further technology adoption by the Fraser Valley industry include:

- Use of apps to measure THI: The use of Thermal Aid and/or other free apps to estimate the level of heat stress in herds is not widespread.
- Fan circulation: Some naturally ventilated barns in the Fraser Valley do not have fans or if fans are present, they are not adequate to provide the appropriate cooling effect. Ensuring that existing and new systems are installed properly could maximize cooling effectiveness and be of considerable benefit to dairy producers. High Volume Low Speed fans are being adopted by some dairy operators, but axial fans remain the most common.
- Exhaust ventilation: No installations of tunnel or cross-flow ventilation systems were identified in the Fraser Valley dairy sector. With an increase in extreme temperatures, the use of these systems is likely to increase in the region.
- Evaporative cooling: There is limited use of sprinklers for cooling, and a relatively small number of dairy producers are using misting (fogging) systems in the Fraser Valley. More information for producers on installation and management of evaporative cooling could enhance effectiveness and/or increase uptake of these systems.
- Conductive cooling: No examples of conductive cooling were identified in the Fraser Valley (although water beds are used in some circumstances). This area of research is new and should be followed closely as study results and new information become available.
- Forage crop management: With warmer and drier conditions, some dairy producers in the Fraser Valley are weighing the costs and benefits associated with investing in irrigation for forage crops. Those that currently irrigate tend to be on sandier soils and have access to a good water supply. Improving soil water retention through practices such as conservation tillage and enhanced organic matter may provide a lower cost option for strengthening resilience to hotter and drier conditions. Additionally, changes to cropping systems – different forage species or varieties – have potential to increase yields and/or heat tolerance.

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[3] This would assist in implementing recommended actions from the 2016 report: BC Ministry of Agriculture, 2016. *Agricultural Building Ventilation Systems*. Publication 306-412-1.

Several opportunities exist to gather more information, undertake knowledge transfer and/or evaluate specific technologies for applicability to the dairy sector in the Fraser Valley. These include:

1. Clarify potential transferability, producer interest and current uptake of heat stress apps. If interest exists, conduct pilots/trials of available heat stress apps (e.g. Thermal Aid) to evaluate their applicability for the Fraser Valley dairy sector.

2. Develop fact sheets that provide technical and economic information for:
    - Installation of variable speed drives
    - Upgrading to High Volume Low Speed fans
    - Various evaporative cooling systems (sprinklers, misters)
    - Radiant barrier insulation installation

3. Further explore the feasibility of conductive cooling technologies through applied research or pilot projects that include cost-benefit analysis.

4. Host field days/farm tours that highlight successful installations/applications of heat abatement technologies and practices, including:
    - Evaporative cooling systems
    - Radiant barrier technologies

5. Support improved forage resilience under extreme heat conditions through:
    - Assessing available information on forage irrigation best practices and water licensing in the Fraser Valley, and addressing any informational gaps in the resources
    - Supporting enhanced distribution of information regarding irrigation and water management/licensing best practices
    - Investigating feasibility of, and constraints on, increased irrigation demand for forage production in the Fraser Valley
    - Conducting on-farm research/pilots of innovative soil and crop management practices that improve forage production under extreme heat
    - Conducting/supporting crop trials and research into new forage varieties or crops

Berry Context and Recommendations

The findings of the stakeholder engagement with berry producers, specialists and researchers confirmed that periods of extreme heat are already having negative impacts on berry yields and quality in the Fraser Valley. However, it was noted that there has not been a shift towards high-tech or investment-heavy methods to mitigate these heat impacts. For many growers, the losses and costs associated with extreme heat have not yet been sufficient to justify investment in new production practices or technologies.

Labour shortages, industry characteristics (e.g. part-time growers, picking for fresh vs. frozen markets), and lack of local demonstration or pilot activity were cited as limiting factors for adoption of new technologies. Nonetheless, extreme heat events will continue to negatively impact yields and quality, and therefore the overall profit of the berry sector in the Fraser Valley. Future increases in summer temperatures, and warmer falls and springs, are likely to increase the willingness to consider additional investments in heat mitigation strategies.

Specific tools and practices that show promise for the Fraser Valley berry sector include:

- Reflective tarps that are used successfully in other BC fruit sectors. More research into the food safety concerns and a cost-benefit analysis of the feasibility of using reflective tarps for each of the berry crops would be beneficial to determine applicability in the Fraser Valley.
- Portable and in-barn cooling systems are effective at quickly cooling berries post-harvest; however, the cost of these systems is high. It may not be economically feasible for one producer to invest in a cooling system, but a cost-sharing scheme may be possible for producers with different harvest schedules.
- There are numerous plant coatings and sprays that could be used to protect berries from damaging UV radiation and to improve overall plant health. More research is needed to the assess qualities of each spray and their applicability to each of the Fraser Valley berry sectors.
- Harvest management practices such as shading harvested fruit or night harvesting could alleviate heat impacts resulting from supply chain bottlenecks.

Several opportunities exist to gather more information, undertake knowledge transfer and/or evaluate specific technologies for applicability to the berry sector in the Fraser Valley. These include:

1. Develop fact sheets that provide technical and economic information for:
    - Use of reflective tarps for various types of berries including specific information for best practices for food safety;
    - Feasibility of in-field/mobile cooling systems

2. Trial the use of sprays and/or coatings for managing heat/sun damage and assess impacts on berry quality. Partner with researchers and/or industry specialists to oversee research and share results via presentation/field days/fact sheets etc.

3. Trial/demonstrate, and provide economic information for, alternative approaches to harvest management, including:
    - Feasibility of night-time (or extended hours) harvest and delivery to packhouses
    - Potential for producer coordination of packhouse delivery timing, with consideration for increased frequency of delivery during extreme heat

4. Undertake a study to evaluate the efficacy and production impacts associated with the use of over-head sprinkler systems for reducing temperatures. Partner with researchers and/or industry specialists to evaluate the potential impacts on pest and disease pressures and water consumption

5. Facilitate dialogue between producers, industry groups, and researchers to develop blueberry cultivar trials for improved heat tolerance and productivity at the latitude of the Fraser Valley.

Summary

As summer conditions continue to shift in the Fraser Valley, heat abatement practices and technologies will become increasingly important for the poultry, dairy and berry sectors. The information in this report is intended to support next steps to enhance development of informational resources, to close research gaps and/or transfer relevant information to producers.

1.0 Project Scope and Methodology

1.1 Project Oversight and Scope

This project identifies current practices for heat abatement in the Fraser Valley and assesses the applicability of technologies and practices that may assist Fraser Valley agriculture producers with managing the impacts of extreme heat, both now and under future climate conditions. Actions to strengthen management for extreme heat were identified in the *Fraser Valley Adaptation Strategies* planning process in 2014-2015. This project was prioritized for implementation when the plan was revisited and updated in 2018 (*Fraser Valley Adaptation Strategies Update)*.

The overall objectives of the project are to:

1. Assess the current state of knowledge, practices and technologies utilized to mitigate the negative effects of extreme heat in the Fraser Valley's dairy, poultry and berry sectors
2. Identify practices and technologies – not currently utilized in the Fraser Valley – that may have promise to mitigate extreme heat impacts
3. Identify regional, sector or farm-level specific steps that could be taken to further assess, promote, and/or enhance adoption of, heat abatement practices and technologies

The project was delivered by Upland Agricultural Consulting with guidance and input from a Project Oversight Committee (POC) that included representation from the BC Blueberry Council (project administrator), the BC Dairy Association, the BC Poultry Association, the BC Agriculture and Food Climate Action Initiative, BC Ministry of Agriculture, the Fraser Valley Regional District and the City of Chilliwack.

1.2 Methodology

1.2.1 Consultation with Key Stakeholders

With input from the POC, a list of key consultation contacts was developed, including producers, industry groups, researchers, and other subject matter experts.

Consultation occurred in two phases:

- Phase 1: Initial outreach was conducted to explore the different heat abatement technologies and management practices adopted within the poultry, dairy, and berry sectors in the Fraser Valley.

- Phase 2: A preliminary draft of the report's findings was shared with select individuals to ensure there were no major gaps in research and to enable an initial round of overall feedback.

Phase 1 Consultation

Phase 1 of stakeholder consultation included at total of 20 interviews and meetings. The consultation included seven on-farm visits at locations in Abbotsford (Sumas and Matsqui), Deroche, Agassiz, and Chilliwack on December 13 and 14, 2018. Additional phone interviews took place between December 10, 2018 and January 31, 2019. A total of ten producers, six industry consultants and equipment specialists and four government staff and researchers were interviewed.

Poultry sector consultation

Six poultry-focused interviews were conducted. Of the eight poultry producers invited to participate in interviews, four agreed to take part in the project. All four of the participating poultry producers raise broilers within the supply management system with varying numbers of birds in each flock cycle. One of the producers also raises turkeys and layers and one also raises broiler breeders. One poultry consultant and one poultry sector equipment dealer were interviewed.

Dairy sector consultation

Eight dairy-focused interviews were conducted. Of the six dairy producers invited to participate in interviews, four agreed to take part in the project. All four participating dairy producers have herd sizes with an average of 200 milking cows. Two dairy equipment specialists were interviewed, along with the BC Ministry of Agriculture dairy specialist and a researcher at the UBC Dairy Research Centre.

Berry sector consultation

Six berry-focused interviews were conducted. Of the seven berry producers invited to participate in interviews, two agreed to participate in the project. One of the participating berry producers grows blueberries, raspberries, blackberries and strawberries and the other producer grows blueberries. One irrigation equipment specialist was interviewed, along with and one industry researcher. The BC Ministry of Agriculture's berry specialist was interviewed, along with an Agriculture and Agri-Food Canada staff member.

Phase 2 Consultation

The goal of Phase 2 of the stakeholder consultation was to ground truth the initial identification of technologies and management practices, gather feedback on their applicability to the Fraser Valley and identify any research gaps. A total of 15 stakeholders participated in this phase of consultation.

The draft report was provided via email to each stakeholder who had participated in the first round of interviews and four of those involved in Phase 1 consultation provided feedback. An additional 11 stakeholders addressed specific follow-up questions, a number of whom were in other jurisdictions, to fact check or fill research gaps. **Feedback from the final round of targeted consultation was integrated into this final report.**

1.2.2 Literature Review and Jurisdictional Scan

The consulting team reviewed materials pertaining to practices and technologies utilized in other jurisdictions to mitigate the impacts of extreme heat. The intent was to identify practices and technologies that show promise for adoption or application in the Fraser Valley, but which are not currently utilized or are underutilized. Approximately 100 resources including government documents, academic articles, news articles and industry reports were reviewed and are documented in footnotes. Some of the most applicable resources are highlighted in Section 5.5.

The literature review helped to identify countries, states, or regions where new technologies and/or practices are being developed and tested. The researched jurisdictions were also selected because high temperatures are more common than historical Fraser Valley conditions, and/or they were identified by stakeholders as being likely to provide transferable/suitable technologies or practices for the Fraser Valley context. The relevant jurisdictions were confirmed with the Project Oversight Committee.

Scanned jurisdictions included:

Poultry sector
- Ontario
- Georgia (USA)
- Alabama (USA)
- United Kingdom
- Netherlands
- Australia

Dairy sector:
- Ontario
- Wisconsin (USA)
- Missouri (USA)
- Kansas (USA)
- Florida (USA)
- Arizona (USA)
- Texas (USA)
- California (USA)
- France
- Australia

Berry sector:
- Washington State (USA)
- Oregon (USA)
- California (USA)
- Utah (USA)
- Chile

Due to time limitations, it was not possible to complete a comprehensive scan of each jurisdiction's entire (poultry, dairy or berry) sector; however, specific examples of technologies and management practices from these regions are provided whenever possible.

1.3 Report Overview and Structure

Heat abatement technologies and practices are described for each sector (poultry, dairy, berry), including those that are commonly used in the Fraser Valley and those that have yet to be widely adopted. A summary of the jurisdictional scan for each technology or practice is provided, followed by an overview of the current level of adoption and potential applicability within the Fraser Valley context.

A summary table of all the technologies and practices reviewed for each sector is also provided for ease of comparison. Finally, conclusions and recommendations to inform next steps for improving informational resources, piloting or demonstrating approaches, or undertaking further research to enhance knowledge of practices/technologies is provided. The information is presented in chapter format to cover each relevant production system sequentially (poultry, dairy, and berry).

2.0 Context for Fraser Valley Extreme Heat Impacts

Average annual temperatures in the Fraser Valley have increased by approximately one degree in the past century and average temperatures are expected to continue to increase in all seasons. Periods of high and extremely hot temperatures (extreme heat events) are also anticipated to occur with greater frequency and intensity.

During the historical baseline period of 1971 to 2000, the average number of days above 25°C for Chilliwack was 38 days per year. By the 2050s, the average number of days above 25°C is projected to double to 76 days. Similar shifts are projected for Abbotsford. More dramatic relative increases are anticipated in average number of days per year above 30°C, with historical baselines of 7 days (Abbotsford) and 8 days (Chilliwack), increasing to an average of 26 and 29 days per year by the 2050s. Table 1 provides a summary of the expected number of days that will reach above 25°C and 30°C in Abbotsford and Chilliwack now and into the future.

TABLE 1 PROJECTED NUMBER OF DAYS PER YEAR ABOVE 25°C AND 30°C IN ABBOTSFORD AND CHILLIWACK.[4]

Community		**1971 – 2000 (Baseline)**	**2020s (Average)**	**2050s (Average)**	**2080s (Average)**
Abbotsford	# days > 25°C	34	52	73	100
	# days > 30°C	7	14	26	45
Chilliwack	# days > 25°C	38	56	76	100
	# days > 30°C	8	16	29	48

The increase in summer temperatures, including periods of high temperature days (above 25°C or 30°C), all present management challenges for agricultural producers in the Fraser Valley. These conditions will become more common over time and require adaptation from the agriculture sector. While management changes may happen incrementally, it is highly likely that current heat management strategies, practices and technologies will not be sufficient to adequately manage these impacts in the future.

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[4] Trevor Murdock, Pacific Climate Impacts Consortium, email communication, December 5, 2018

3.0 Poultry Sector

3.1 Overview of Heat Impacts on the Poultry Sector

Heat stress in poultry is the result of a combination of factors including air temperature, humidity, and age of the flock[5]. Sudden spikes in temperature are more dangerous than a gradual rise in temperature for poultry[6]. The Thermal Neutral Zone (TNZ), an established temperature range in which poultry do not need to alter basic metabolic rates or behaviour to maintain body temperature, is 13°C to 24°C [7]. Production performance of broilers is optimized at a range of 18°C to 23°C. Laying hens can perform well at higher temperatures, with stress occurring at temperatures above 26°C. At temperatures above 38°C, mortality of all poultry types is likely to occur.

Relative humidity (RH) plays an important role in heat stress. As a general rule, higher RH results in more stress. The RH impacts the ability of the flock to shed heat through respiration and evapotranspiration. As such, it is recommended that the RH in barns remain below 80% during periods of extreme heat[8].

The National Farm Animal Care Council publishes a Code of Practice for the care and handling of various type of poultry[9]. The Code's guidelines for optimal broiler breeder and broiler chicken production temperature ranges, measured at bird level and assuming 50-70% relative humidity, are presented in Table 2:

TABLE 2. OPTIMAL TEMPERATURE RANGES FOR BROILER PRODUCTION BASED ON BIRD AGE.

Bird Age	Temperature Range
1-7 days	30-34°C
1-5 weeks	Lower by 2-3°C each week
6 weeks on	18-24°C

The Code's general guidelines for optimal turkey barn temperature ranges, measured at bird level and assuming 50-70% relative humidity, are presented in Table 3:

TABLE 3. OPTIMAL TEMPERATURE RANGES FOR TURKEY PRODUCTION BASE ON TURKEY AGE.

Turkey Age	Temperature Range
1-7 days	32-35°C
1-5 weeks	Lower by 2-3°C each week
6-10 weeks	15-24°C
11 weeks on	13-24°C
Breeders	7-24°C

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[5] Pawar, S. S., Sajjanar, B., Lonkar, V. D., Kurade, N. P., Kadam, A. S., Nirmal, A. V., and Bal, S. K. 2016. Assessing and mitigating the impact of heat stress on poultry. *Adv. Anim. Vet. Sci*, *4*(6), 332-341.

[6] Heat Stress in Poultry, Solving the Problem. 2005.Government of United Kingdom

[7] Jini, D., Bhagawati, K. Bhagawati, R. and Rajkhowa, D.J. 2015. Identification of critical periods environmentally sensitive to normal performance of Vanaraja poultry breed in climatically different locations. International Letters of Natural Sciences. Vol. 46, p76-83.

[8] Tunnel Ventilation in Livestock Barns – With and Without Evaporative Cooling. 2018. Ontario Ministry of Agriculture, Food and Rural Affairs.

[9] National Farm Animal Care Council. 2016. Code of Practice for the Care and Handling of Hatching Eggs, Breeders, Chicken, and Turkeys.

The Ontario Poultry Industry Council provides similar guidelines for older birds (Table 4). Due to their size, older birds are at a greater risk of heat-related impacts, whereas turkeys are more tolerant of heat and humidity than chicken layers and broilers. Broilers nearing the end of their growth cycle (days 35-41) are the most vulnerable to extreme heat.

TABLE 4. HEAT STRESS VALUES OF TEMPERATURE AND RELATIVE HUMIDITY IN OLDER BIRDS[10].

	Temperature (°C)	Relative Humidity (%)	Stress Level
Broiler	20	40 - 95	No Stress
	22	50 – 85	Alert
	24	40 - 50	
	24	55 +	Danger
Layer	20 - 22	40 +	No Stress
	24	40 - 70	
	26	40	
	24	75 +	Alert
	26	45 - 60	
	26	65 +	Danger
Breeder	20	40 - 90	No Stress
	22	50 +	Alert
	24	40 – 80	
Turkey Hen	20 – 22	40 +	No Stress
	24	65 – 90	Alert
	26	40 - 60	
	26	65 – 75	Danger
Turkey Tom	20	40 +	No Stress
	22	40 – 85	
	24	55 +	Alert
	26	40 -75 +	

Although layers, broilers and turkeys all have varying levels of heat tolerance, common signs of heat stress include increases in respiration rate, reduction in food intake, and changes in behaviour (e.g. the birds spend more frequent periods laying down than standing). Other heat stress impacts include reduced fertility, digestive system problems, and thinner eggshells[11].

3.2 Heat Abatement Technologies and Management Practices for Poultry

The effects of heat stress on poultry can be managed by monitoring temperature and humidity levels, implementing properly designed and operated ventilation systems, and employing effective evaporative cooling strategies. These are each described below, in addition to a discussion managing flock densities and electrolyte supplementation. Most technologies discussed in this report are most applicable to large-scale commercial poultry operations, while lower cost technologies and management practices could also be applicable smaller-scale commercial poultry operations.

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[10] Price, K. and S. Dulmelis. Beat the Heat: Managing Poultry Stress. Poultry Industry Council. (Video)

[11] Ibid.

3.2.1 Using the Temperature-Humidity Index (THI) as an Indicator of Poultry Heat Stress

Measuring flock heat stress can be accomplished at the farm level by installing temperature and humidity sensors (hygrometers) to measure and monitor climate data in barns. Cooling systems can be programmed and/or adjusted remotely to achieve desired barn conditions[12]. Alternatively, apps can be downloaded to track current and forecasted climate data from nearby weather stations to calculate the THI.

Automated climate control systems require an initial investment for installation, but provide a return based on improved flock production, performance and health. Automated barn climate management can limit temperature and humidity swings within a narrow optimum range. For example, an electronic controller can maintain the target in-barn temperature within 1.1°C of the desired temperature[13].

Integrated controllers also eliminate the labour of changing settings on separate controls for ventilation or evaporative cooling systems and can be utilized remotely. However, diligent maintenance and management are still required to oversee and operate an integrated control system. An important component of a good integrated controller is adequate built-in protection against power spikes and surges. A good climate control system will also include zoning capability, allowing producers to place climate sensors in various parts of the barn for more precise control.

Apps have been developed that can automatically calculate THI based on local weather station data and/or thermometer-hygrometer readings at the farm. The apps can be used to determine THI without calculations or referral to printed THI charts. In addition, the apps will automatically classify the degree of heat stress based off the THI value obtained.

The University of Guelph and the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) jointly developed a free app that allows poultry producers to calculate the THI using real-time inputs of temperature and relative humidity, or by inputting the forecasted parameters for later in the day (Figure 1). Based on the results, the app then provides management options for reducing heat stress. According to the app's developers, it has been used by producers in Ontario, Nova Scotia and parts of the Middle East, such as Israel[14]. A THI app developed in France, called "ThermoTool", helps producers evaluate the risk level of heat stress in poultry (English language settings are available)[15].

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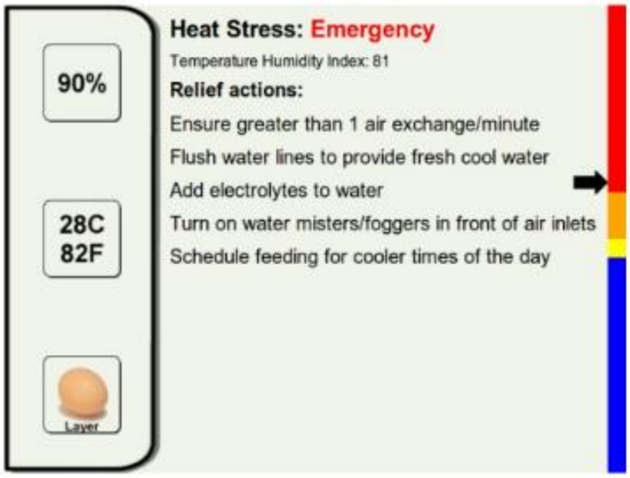
[12] Precision Dairy Farming. University of Kentucky.

[13] Donald, J. O. 2010. Environmental Management in the Broiler House. Ross Environmental Management.

[14] Interview with OMAFRA Poultry Specialist.

[15] New App to evaluate heat stress in poultry farms. 2015. Poultryworld.net.



Heat Stress: Emergency

Temperature Humidity Index: 81

Relief actions:

Ensure greater than 1 air exchange/minute

Flush water lines to provide fresh cool water

Add electrolytes to water

Turn on water misters/foggers in front of air inlets

Schedule feeding for cooler times of the day

FIGURE 1. EXAMPLES OF MANAGEMENT ACTIONS FOR LAYERS PROVIDED BY THE OMAFRA HEAT STRESS APP[16].

Current and Future Applicability to Fraser Valley Producers

Many of the large-scale poultry operations in the Fraser Valley have already installed automated climate controls in barns. The rate of adoption appears to be lower among smaller producers[17]. The level of adoption of apps is uncertain. However, anecdotal evidence suggests that relatively few producers are using the apps, which could be a natural complement to automated climate control systems.

3.2.2 Ventilation

The most effective way to cool a flock when temperature and relative humidity rise in the barn is to circulate hot air out of the barn and replace it with fresh, cooler air. Speeding up the movement of air through the barn will create a wind-chill effect and cool the flock. Evaporative cooling systems, such as cooling pads and misters, can be added to ventilation systems to provide a further reduction in barn temperatures (see following section 3.2.3 for a description of evaporative cooling technologies)[18]. The two most common ventilation systems used in poultry production are natural ventilation and exhaust (tunnel and cross) ventilation.

Natural Ventilation

Natural ventilation systems in poultry barns use side wall openings (and in larger barns, end wall openings) to allow fresh air to flow in and out, similar to natural ventilation used in dairy barns (Figure 14). These openings are fitted with curtains or moveable walls that can be opened or closed to control air flow. Chimneys or vent openings are designed for naturally-ventilated barns, incorporating roof peaks and adjustable baffles to control the air flow rates. Natural ventilation is usually sufficient to maintain indoor temperatures within 3°C to 6°C of outdoor temperatures.

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[16] Ontario Ministry of Agriculture Food and Rural Affairs. Heat Stress in Livestock and Poultry App.

[17] Fraser Valley Equipment specialist feedback.

[18] The Perfect Climate Controller. 2014. Canadian Poultry.

Natural ventilation is commonly used by small and medium scale poultry producers but is not used in large-scale broiler and layer operations, as it does not provide sufficient cooling for larger numbers of birds during extreme heat[19].

Tunnel and Cross Ventilation

Tunnel and cross ventilation systems are fully enclosed and designed for maximum airflow by adjusting air intake volume and fan speed. For additional cooling, high-pressure misting systems or cooling pads are added into the barn (see section 3.2.3). Tunnel ventilation refers to an exhaust ventilation system installed along end walls, while cross-ventilation refers to exhaust fans along side walls. Both are described below.

Tunnel Ventilation
In tunnel ventilation, an air inlet is located on one end wall of the barn with exhaust fans located on the opposite end. Air moves at a high velocity down the long axis of the building, similar to a wind tunnel (Figure 2). This provides a beneficial wind chill effect that cools the flock by convection and exhausts this heat out of the building[20]. The velocity of air moving across the flock will determine the extent of cooling inside the barn. When tunnel air velocity is in the range of 1.7 - 2 m/s, the air in the barn can be 4 - 8°C cooler in the barn than outdoors[21,22] (Figure 3). Tunnel ventilation systems can be automatically programmed to respond to rising outdoor temperatures through increased intake volumes and increased fan speeds. Tunnel ventilation can also be coupled with cooling pads to further decrease barn temperatures (Figure 4) (cooling pads discussed in Section 3.2.3).

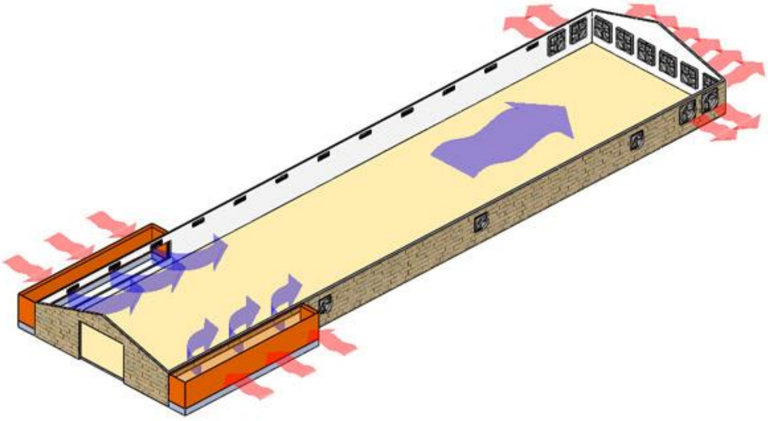

FIGURE 2. AIR FLOW WITHIN A TUNNEL VENTILATION BARN SYSTEM – AIR ENTERS AT ONE END OF THE BARN AND EXISTS THE OTHER[23].

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[19] BC Ministry of Agriculture, 2016. Agricultural Building Ventilation Systems. Publication 306-412-1.

[20] Tunnel Ventilation in Livestock Barns – With and Without Evaporative Cooling. 2018. Ontario Ministry of Agriculture, Food and Rural Affairs.

[21] Tunnel Ventilation of Broiler Houses. 2018. University of Florida Extension. R. A. Bucklin, J. P. Jacob, F. B. Mather, J. D. Leary, and I. A. Naas.

[22] Donald, J. O. 2010. Environmental Management in the Broiler House. Ross Environmental Management

[23] Poultry Simulator, 2019. Efficient environmental management for poultry: Tunnel ventilation air flow simulator.

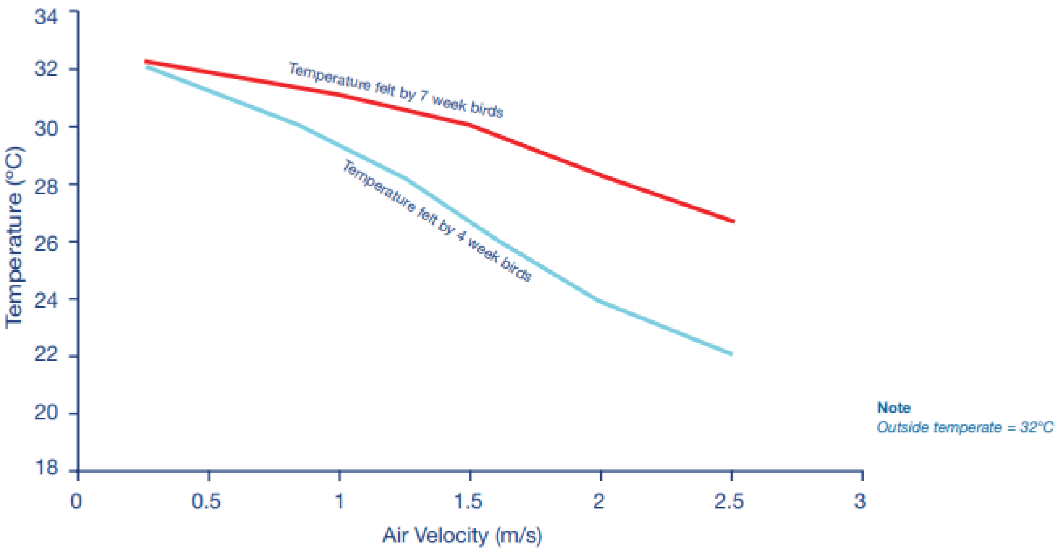

FIGURE 3. THE WIND-CHILL EFFECT DUE TO AIR VELOCITY IN TUNNEL VENTILATED BARNS[24].

FIGURE 4. TUNNEL VENTILATION, INLET WITH EVAPORATIVE COOLING PADS INSTALLED (LEFT) AND EXHAUST FANS (RIGHT)[25].

Cross Ventilation

Cross ventilation systems use air inlets that draw air into the barn and exhaust fans to move air out of the barn through side walls. As outdoor temperatures increase, automated controllers increase the fan speed and open up the air inlets to increase airflow. In a cross-flow ventilation system with a slot-type air inlet, the air speed at the animal level ranges from 0.25 to 0.50 m/s[26] (Figure 5).

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[24] Donald, J. O. 2010. Environmental Management in the Broiler House. Ross Environmental Management.

[25] Tunnel Ventilation in Livestock Barns – With and Without Evaporative Cooling. 2018. Ontario Ministry of Agriculture, Food and Rural Affairs.

[26] Ibid.

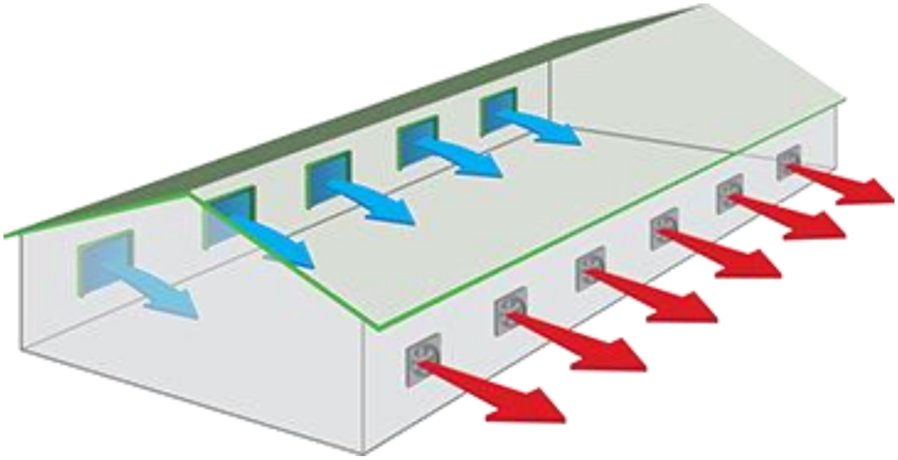

FIGURE 5. CROSS VENTILATION. (SOURCE: KAISER POULTRY, 2019)

Ventilation research and extent of implementation in Ontario, Alabama (USA), Georgia (USA), the United Kingdom and the Netherlands were reviewed. These jurisdictions have relatively large poultry industries that are exposed to extreme heat conditions and were identified by Fraser Valley industry experts as having potential applicability for the local context.

Research from Auburn University in Alabama indicates that when outdoor temperatures consistently rise into or above the 24-30°C range, tunnel ventilation systems should be installed[27]. Tunnel ventilation systems are common in poultry barns in Ontario, Georgia and the United Kingdom[28]. Cross-flow ventilation is also used in Ontario[29]. No literature indicated use of natural ventilation in Georgia, Ontario or Alabama, likely because temperatures and RH are too high for natural ventilation systems to provide the required cooling.

Current and Future Applicability to Fraser Valley Producers

In 2016, a study examining agricultural building ventilation systems in BC was completed, including interviews with equipment suppliers and veterinarians active in the BC poultry industry[30]. The study's findings align with the results from interviews conducted for this project – tunnel ventilation and cross ventilation are becoming the most widely adopted practices for the BC and the Fraser Valley poultry industry (Table 5).

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[27] Donald, J. O. 2010. Environmental Management in the Broiler House. Ross Environmental Management.

[28] Getting ventilation right on broiler farms. 2018. Poultry World

[29] Cross-ventilation barn design for poultry: A North American first. 2017. Canadian Poultry.

[30] BC Ministry of Agriculture, 2016. Agricultural Building Ventilation Systems. Publication 306-412-1.

TABLE 5. USE OF VENTILATION SYSTEMS IN POULTRY OPERATIONS IN BC. (SOURCE: BC MINISTRY OF AGRICULTURE)

Ventilation Systems for Existing Poultry Barns			
	Layers	**Turkeys**	**Broilers**
Natural	Rare	Common	Rare
Tunnel	Uncommon	Rare	Common
Cross	Rare	Very Common	Very Common
Ventilation Systems for New Poultry Barns			
	Layers	**Turkeys**	**Broilers**
Natural	N/A	Uncommon	N/A
Tunnel	Common	Common	Very common
Cross	Very Common	Common	Common

Natural ventilation systems are still used for small-scale broiler and layer production, as well as large-scale turkey production in the Fraser Valley, but producers are moving towards tunnel ventilation systems for more control over barn conditions[31]. Some older, wider barns with natural ventilation are being retrofitted to increase cooling potential by adding air inlets and fans on side walls to allow for fresh air to enter the barn from both sides[32]. The cost-effectiveness of retrofitting barns with tunnel ventilation that currently use cross ventilation depends on the length of the barn. Barns that are 150 m long are less expensive to retrofit because they are long and narrow which is conducive to creating the wind tunnel effect. Barns that are 60-90 m long may cost 20-30% more to retrofit due to the extra equipment needed to move air faster in smaller barns as the smaller barns are usually wider[33]. Tunnel ventilation may become more common for layer and turkey production as the number of days 25°C and over continues to rise[34].

3.2.3 Evaporative Cooling

Evaporative cooling technologies use water to bring down the ambient air temperature within the barn. These technologies work best when RH is relatively low. At high humidity, the air is already saturated with water vapour and the technologies are less effective. The two main types of evaporative cooling systems used in poultry operations are cooling pads and high-pressure misters. Each are described in more detail below.

Evaporative Cooling Pads

Cooling pads can be used in ventilation systems in combination with exhaust fans and are particularly common in tunnel ventilated barns. The evaporative cooling pad is made of fibrous material woven together, similar to corrugated cardboard, with large gaps in the grooves. The pad is mounted vertically over the tunnel air intake. The bottom of the pad sits in a drain trough and a water delivery pipe with evenly spaced holes runs across the top of the pad. Water is pumped from the trough at the bottom of the pad to a distribution pipe at the top of the pad, and trickles down the face of the pad to wet it[35]. The water then evaporates into the air entering the barn, lowering the temperature of the air. The amount of water the

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[31] BC Ministry of Agriculture, 2016. Agricultural Building Ventilation Systems. Publication 306-412-1.

[32] Interviews with Fraser Valley Equipment Specialists. This is the specific feedback regarding retrofitting poultry bans for tunnel ventilation. Smaller barns are more expensive to retrofit because they are wider, and it is move difficult to get the wind-chill effect with wider barns.

[33] Ibid.

[34] Stakeholder interview with poultry producer.

[35] BC Ministry of Agriculture, 2016. Agricultural Building Ventilation Systems. Publication 306-412-1.

evaporative cooling pads will use is primarily dependent upon three factors: outside temperature, outside humidity and the amount of air being drawn through the evaporative cooling pads[36].

These high-efficiency systems are low maintenance and do not risk adding moisture directly to the flock or to bedding/litter[37]. Automated thermometers can be used to trigger the operation of the cooling pads. Equipment specialists recommended using cooling pads when indoor barn temperatures reach 25°C[38]. However, the pads do require regular inspection to minimize algal growth and accumulation of dirt and minerals on the pads. Winterizing requires draining the water supply system and covering the air inlet.

Samples of evaporative cooling pad performance (in Table 6) are provided in the previously referenced study of ventilation system use in BC agriculture. In this modelling example, the flow rate of water being evaporated is calculated based on measuring the initial temperature (outdoor air intake), increasing the relative humidity to 60% with the cooling pad, and re-taking the temperature (cooled air into barn). In this example, the water flow rates were based on an inlet air flow rate of 50 m^3/s (about 106,000 cubic feet/minute (CFM)) and temperatures inside the barn were lowered 5-10°C.

TABLE 6. EVAPORATIVE COOLING PAD PERFORMANCES[39].

Location and Circumstance	Outdoor Air at Intake			Cooled Air into Barn			Water Flow L/hr
	Dry bulb °C	Wet bulb °C	RH	Dry bulb °C	Wet bulb °C	RH	
Abbotsford summer day	29	20	42%	25	20	60%	310
Abbotsford hottest on record	38	23	25%	28	23	60%	770

While cooling pads are efficient at lowering the in-barn temperatures, they will increase the RH within the barn and require sufficient water supply. Relative humidity should never exceed 80% during warm weather, as this will cause the animals more distress[40].

High Pressure Misters

High-pressure misting systems (or foggers) produce fine water droplets that are discharged into the barn's fresh supply air[41]. A booster pump is required for this system as water pressure required for operation is up to 7,000 kPa (about 1000 psi). Misting systems can be attached to fans, directing the mist above feeding and high-traffic areas (Figure 6, Figure 7). They can also be used in cross-ventilated barns by locating the nozzles on the inlet side and cooling the air before it reaches the birds. Often high-pressure misting systems are automated and activate at a certain temperature for short periods, to ensure humidity levels are controlled. A source of clean water is needed, and system maintenance requires additional labour[42]. These systems are also used in dairy barns.

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[36] Poultry Housing Tips - Evaporative Cooling Pad System Water Usage. 2017. The University of Georgia. College of Agriculture and Environmental Sciences.

[37] Ibid.

[38] Ibid.

[39] BC Ministry of Agriculture, 2016. Agricultural Building Ventilation Systems. Publication 306-412-1.

[40] Tunnel Ventilation in Livestock Barns – With and Without Evaporative Cooling. 2018. Ontario Ministry of Agriculture, Food and Rural Affairs.

[41] BC Ministry of Agriculture, 2016. Agricultural Building Ventilation Systems. Publication 306-412-1.

[42] Ibid.

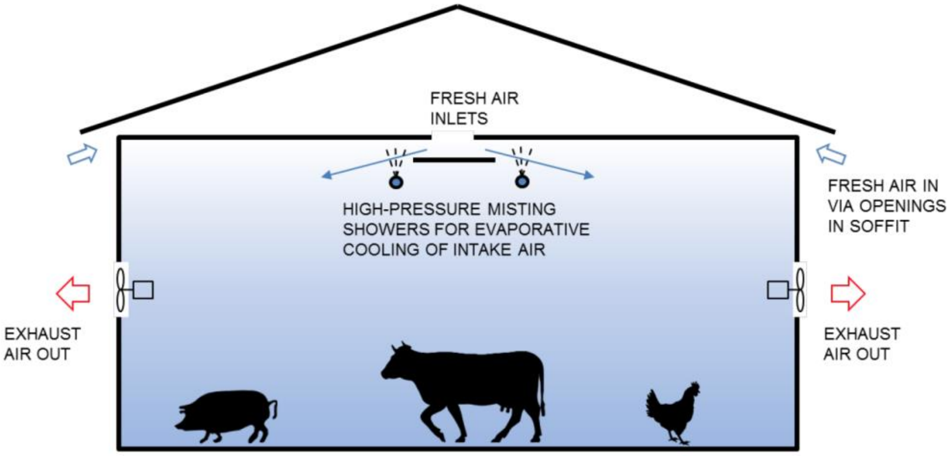

FIGURE 6. SCHEMATIC OF BARN MISTING OR FOGGING SYSTEM AND AIR FLOW[43].

High-pressure misting systems have been shown to be capable of lowering indoor barn temperatures by 5-10°C [44]. For example, a 50,000-bird broiler barn in the United Kingdom documented a drop-in temperature from 30 °C to 25°C in five minutes using high-pressure misters attached to fans[45].

FIGURE 7. HIGH-PRESSURE MISTING SYSTEM IN A POULTRY BARN[46].

In regions with both high temperatures and humidity levels, such as the southern United States[47] (e.g. California, Texas, Alabama, Florida, Georgia), evaporative cooling pads are frequently used in poultry barns. Misters are also used extensively in the United States (in particular in Alabama, Georgia, and California), in Ontario, and in the United Kingdom. A study conducted at Auburn University in Alabama, found that when

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[43] BC Ministry of Agriculture, 2016. Agricultural Building Ventilation Systems. Publication 306-412-1.
[44] Cooper, O. 2009. Misting system helps combat heat stress in chickens. Farmers Weekly.
[45] Ibid.
[46] Cubo fogging systems. Image of Cubo system with fogger in a poultry barn.
[47] BC Ministry of Agriculture, 2016. Agricultural Building Ventilation Systems. Publication 306-412-1.

outside temperatures rise to 35°C, the wind-chill effect of tunnel ventilation begins to disappear, and evaporative cooling must be added to reduce air temperature in the barn[48].

Current and Future Applicability to Fraser Valley Producers

In the Fraser Valley, evaporative cooling pads are common in broiler operations with tunnel ventilation[49]. Cooling pads are less common with cross-ventilation due to the large surface area where the cooling pads are needed (i.e. across the whole side of a barn). Local equipment specialists often recommend cooling pads rather than high-pressure misting systems because they are easier to manage and maintain[50]. As tunnel ventilation becomes more common across the sector (i.e. with layer and turkey operations), cooling pads are also likely to increase in use.

The effectiveness of evaporative cooling systems is determined by how efficient the system is in evaporating water. This means that the lower the relative humidity, the greater the cooling potential of the system. The cooling effects of misting and cooling pads are presented in Table 7 based on outdoor air temperatures and RH[51]. While reduction of barn temperature of as much as 11°C are possible with cooling pads, 6°C is more typical in humid climates[52].

TABLE 7. EFFECTIVENESS OF EVAPORATIVE COOLING SYSTEMS (MISTERS OR COOLING PADS) BASED ON RELATIVE HUMIDITY[53].

Outside air temperature (°C)	Resulting air temperature (°C) for given relative humidity in the barn		
	RH = 40%	**RH = 50%**	**RH = 60%**
38.7	28.9-32.2	30.6-33.3	32.2-34.4
35.0	26.7-29.4	28.3-30.6	29.4-31.7
32.2	24.4-27.2	26.1-28.3	27.2-28.9

Some equipment specialists in the Fraser Valley are reluctant to recommend misting systems due to the potential difficulty of managing RH within the barn. However, other equipment specialists noted that misters are effective if managed properly, and that in barns with cross-flow ventilation, misters are still relatively common in the Fraser Valley (i.e. within the layer and broiler operations)[54]. As cooling pads become more common, they may replace misting systems within Fraser Valley poultry barns.

3.2.4 Ground Source Heat Pump

Heat pumps can be used for both the cooling and heating of poultry barns. For cooling, a ground source (or geothermal) heat pump extracts thermal heat from the barn and releases it into a collection tank of water in the ground. Key features of the pump include a refrigerant compressor, water recirculation pump, and electricity to power the compressor (Figure 8)[55]. The system relies on the flow of a coolant, such as glycol, in a closed loop that is buried in the ground. During the summer, the barn is cooled by transferring the thermal energy to a collector (essentially a tank of water) stored in the ground. Because soil can absorb

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[48] Donald, J. O. 2010. Environmental Management in the Broiler House. Ross Environmental Management.
[49] BC Ministry of Agriculture, 2016. Agricultural Building Ventilation Systems. Publication 306-412-1.
[50] Interviews with Fraser Valley Equipment Specialists.
[51] BC Ministry of Agriculture, 2016. Agricultural Building Ventilation Systems. Publication 306-412-1
[52] Ibid.
[53] Donald, J. O. 2010. Environmental Management in the Broiler House. Ross Environmental Management.
[54] BC Ministry of Agriculture, 2016. Agricultural Building Ventilation Systems. Publication 306-412-1.
[55] Fully-packaged ground source heat pumps – designed specifically for the poultry industry. Poultry Heating and Cooling.

heat more effectively than air, heat pumps are more efficient than air source heat pumps. During the winter, systems can be reversed so that heat is removed from the collector and transferred into the barn.

A heat pump may be able to transfer up to three times more energy than is required for its operation and has very low operating costs; however, installation and maintenance costs are high. Horizontal closed loop systems require land because the collector tank and piping must be buried underground in trenches approximately 1.8 m deep and up to several hundred metres long. If land is unavailable, vertical loops may be buried up to 100 m deep. In either case, an increase in electrical service may be needed to meet pump and compressor needs[56].

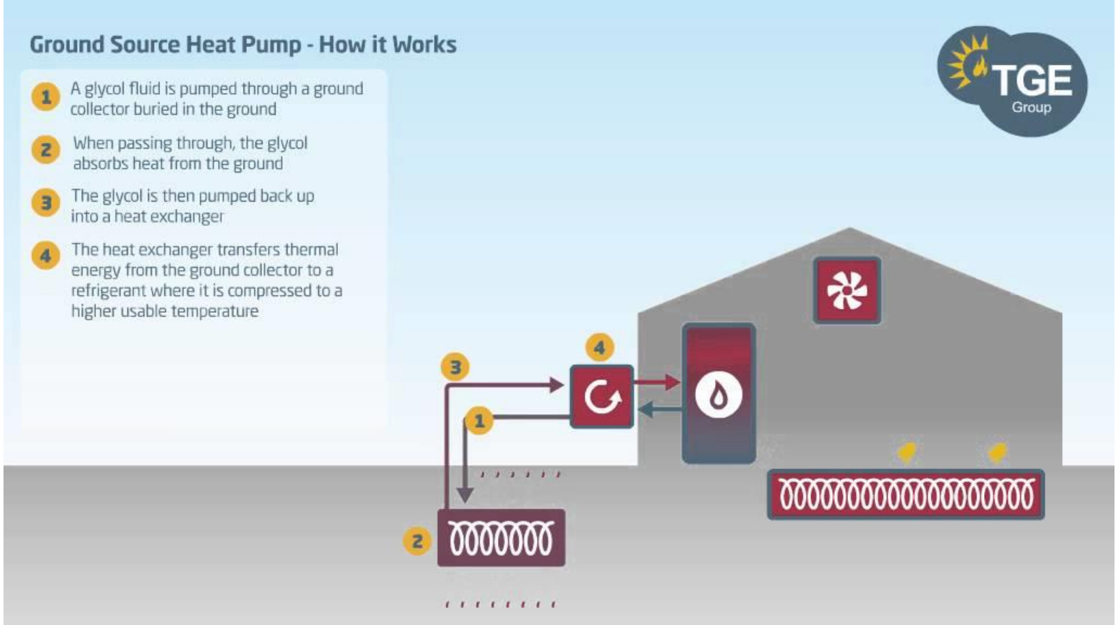

FIGURE 8. GROUND SOURCE HEAT PUMP PROCESS[57].

Heat pumps are used to cool (and heat) poultry barns in the United Kingdom[58,59]. Recently, four new barns housing 200,000 broilers were constructed with heat pumps to provide both cooling and heating functions[60]. The heat pump system uses 1.2 megawatts of power and took over four months to install, using 30,000 m of horizontal ground collectors. The passive cooling from the heat pumps removes excess heat via underfloor pipework and fan coils. The circulation pumps the return it to the ground where it is stored for future heating cycles.

Interest in heat pumps is also building in Australia[61], and the United States. Researchers at the University of Missouri recently developed a geothermal energy system for a large turkey farm in that state. The project was funded by the US Department of Energy, in partnership with the farm's owner, as a demonstration project[62].

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[56] BC Ministry of Agriculture, 2016. Agricultural Building Ventilation Systems. Publication 306-412-1.
[57] TGE Group, United Kingdom. Heat pump case studies
[58] Ibid.
[59] IPT Poultry Heating Cooling. Case studies – our latest projects.
[60] Ibid.
[61] Geothermal energy – what is it and what are the opportunities? 2013. The Poultry Site.
[62] Ibid.

Current and Future Applicability to Fraser Valley Producers

Some Fraser Valley producers have expressed interest in the potential of ground source heat pumps for heat abatement (and their combined role for winter heating). However, no examples of heat pumps in Fraser Valley poultry operations were identified through stakeholder consultations or research. While producers and equipment specialists understand that the technology is very costly to install, there is also interest in the potential energy cost savings, for both cooling and heating needs, over the long term.

3.2.5 Managing Flock Densities

Adjusting flock densities is a management practice that can be used to manage heat impacts. With higher stocking densities, air circulation is restricted, and heat removal is reduced[63]. The effect that flock density can have on the temperature of broilers can be seen in tunnel-ventilated houses with evaporative cooling pads during hot weather (Figure 9). Indoor barn temperatures are lower at the evaporative cooling pad end of the barn, which attracts more birds, resulting in higher densities in that area of the barn and eventually higher temperatures.

While an automated climate control system may be keeping the temperature in the barn within a degree or two, differences in density result in the effective temperature being experienced by a flock as much higher. To avoid uneven flock densities and temperatures within the barn, migration fences can be installed at regular intervals (e.g. every 30 m) to discourage congregation.

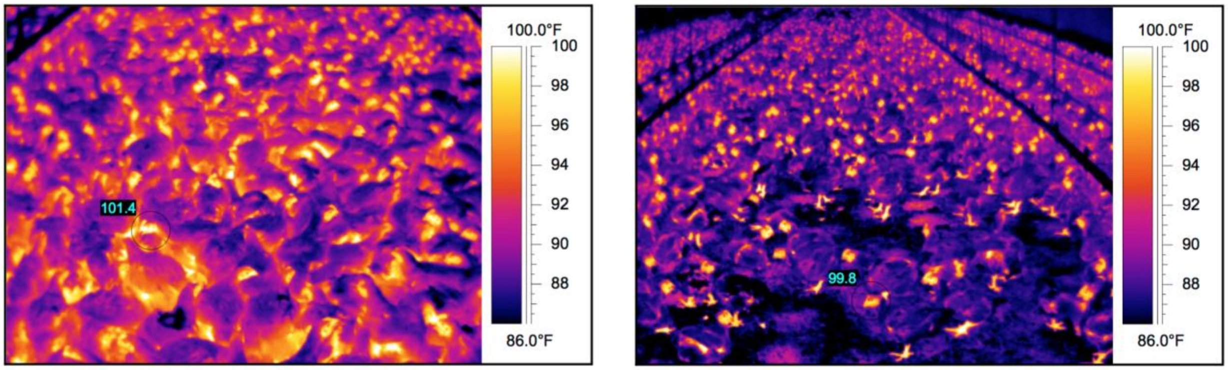

FIGURE 9. EXAMPLES OF DIFFERENT DENSITIES IN THE SAME TUNNEL VENTILATED BARN – HIGH DENSITY ON THE LEFT AND LOW DENSITY ON THE RIGHT[64].

Research consistently indicates that the health and welfare of broilers is compromised if stocking densities are higher than 34-38 kg/m^2 (depending on final body weight)[65]. Research on optimal stocking densities has been conducted for decades and some jurisdictions have established codes of practice for stocking densities to ensure bird welfare[66]. Research from the University of Georgia shows that optimal stocking densities will vary, depending on the internal barn environment and the ventilation and cooling systems in

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[63] Czarick, M., Lin Teo, M., and Fairchild, B., 2018. Poultry Housing Tips - Density Can Have More of an Affect on Body Temperatures Than Air Temperature. The University of Georgia, College of Agriculture and Environmental Sciences.

[64] Ibid

[65] Estevez, I. 2007. Density Allowances for Broilers: Where to Set the Limits?, Poultry Science, Volume 86, Issue 6, Pages 1265–1272

[66] Code of Practice for the Care and Handling of Hatching Eggs, Breeders, Chicken and Turkeys. 2016. National Farm Animal Care Council.

place[67]. The jurisdictional scan was inconclusive about how common the use of stock density management is for mitigating high temperatures, or uneven temperatures, in the barn environment.

Current and Future Applicability to Fraser Valley Producers

Within BC's supply managed system, maintaining required levels of production is critical and ensures consistent availability of poultry products. To achieve this, tight production schedules are developed well in advance and may not provide enough flexibility for producers to adjust stocking densities. However, the installation of migration fences could prevent uneven densities within the barn without altering the overall flock size. More local research is required to determine if this management practice would be feasible, and beneficial for reducing heat stress, within the Fraser Valley production context.

3.2.6 Electrolyte Supplements

As mentioned previously, heat stress in poultry is expressed through a reduction in feed consumption and an increase in respiration, resulting in dehydration. In periods of high heat, producers can adjust nutrient densities in the water and/or feed accordingly[68]. Electrolytes (e.g. sodium, potassium, and chloride) in the amounts of 230-250 mEq/kg are recommended in broiler or layer feed during periods of high temperatures[69]. Similarly, the US National Research Council recommended 0.2% sodium, 0.3% potassium, and 0.2% chloride for initial growth phases and lower doses for the finishing phase[70]. Disadvantages of adding electrolyte supplements include an increase in water consumption and higher litter moisture.

Electrolyte supplements are widely used within the poultry industry, regardless of jurisdiction[71].

Current and Future Applicability to Fraser Valley Producers

Fraser Valley producers use electrolyte supplements for their feed and water in advance of heat events. Many resources are already available to provide guidance and information to producers for determining optimal levels of supplements in feed and water, including veterinarians and industry specialists.

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[67] Czarick, M., Lin Teo, M., and Fairchild, B., 2018. Poultry Housing Tips - Density Can Have More of an Affect on Body Temperatures Than Air Temperature. The University of Georgia, College of Agriculture and Environmental Sciences.

[68] For example, to compensate for the reduced feed intake under heat stress, dietary allowances for electrolytes may be increased by 1.5% for each 1 °C rise in temperature above 20 °C. Dietary requirement of sodium, potassium and chloride is 0.20-0.25 %, 0.24-0.30% and 0.30 %, respectively.

[69] Suganya, T., Senthilkumar, S., Deepa, K., & Amutha, R. (2015). Nutritional management to alleviate heat stress in broilers. *Inter J Sci EnDVOi Techno*, *4*, 661-666.

[70] Mushtaq, M. M. H., Pasha, T. N., Mushtaq, T., & Parvin, R. (2013). Electrolytes, dietary electrolyte balance and salts in broilers: an updated review on growth performance, water intake and litter quality. World's Poultry Science Journal, 69(4), 789-802.

[71] Interviews with industry specialists and producers.

3.3 Summary Table of Technologies and Management Practices for the Poultry Sector

Technology or Practice	Jurisdictions	Costs	Weaknesses	Strengths
Automated Climate Controls and Apps	BC, Fraser Valley and other regions Ontario Nova Scotia Georgia United Kingdom Israel	Cost of automation depends on size of the barn. Average cost is approximately $10,000 per barn[72]. Apps are free or very low cost.	Automated systems and apps are only as efficient and accurate as the data that they are using. Data from farm weather stations or internal barn sensors are best. Requires WIFI connectivity. Require ventilation and cooling systems that are compatible with automation systems. Need to ensure the apps are suitable for use in the Fraser Valley climate conditions.	Allows for precision management of barn conditions which provides proactive (data-driven) heat mitigation. Automation may free up producer time otherwise spent managing barn conditions. Apps provide quick feedback on barn conditions and management actions to reduce heat stress. Easy to use and can be used remotely.
Natural Ventilation	BC, Fraser Valley and other regions, turkey barns and small-scale operators.	Highly variable depending on barn specifics[73].	Very likely these systems will not provide adequate cooling in future conditions without additional mechanical or exhaust-based air circulation for ventilation/ evaporative cooling.	Least expensive form of ventilation.

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[72] Interview with Fraser Valley equipment specialist.

[73] Specific costs for side wall or end wall curtains, chimneys and ridge vents are difficult to individually ascertain. There are several types of curtains used in dairy barn design. See equipment dealers for more information.

Technology or Practice	Jurisdictions	Costs	Weaknesses	Strengths
Tunnel Ventilation	BC - Fraser Valley for broilers Ontario Georgia Alabama United Kingdom The Netherlands	$40,000-80,000, for a new barn including evaporative cooling pads [74]. Specific costs are determined by the length of the barn and how many air inlets and exhaust fans are needed to achieve the desired air speed.	Not suitable for use with chicks or when temperatures dip to 15°C and lower. Requires training to ensure efficient system performance and maintenance. May result in greater impacts of dust, odour and noise on neighbouring properties.	Proven to be effective at reducing temperatures in the barn, up to a 4-8°C drop[75] [76]. Ideal system for installing cooling pads for extra temperature reduction during extreme heat.
Cross Ventilation	BC - Fraser Valley for broilers Ontario Alabama United Kingdom The Netherlands	Unable to provide a range of costs due to a high number of variables (e.g. barn size, fan type and number of fans).	This system cannot provide the same level of cooling during extreme heat as tunnel ventilation. Not preferred in areas of high humidity. More challenging to add evaporative cooling pads.	Provides fairly effective temperature control and good air quality[77]. Allows for a shorter and wider barn design than tunnel ventilation.
Evaporative Cooling pads	BC - Fraser Valley Ontario Georgia Alabama California	Individual costs of the pads are low, approximately $20, however multiple pads are required for each barn and installation costs may be high. Cooling pad costs are typically included in expenses related to construction of a tunnel-ventilated barn.	Requires regular maintenance and inspection to prevent algal buildup. Recommended to be turned off overnight. Needs to be winterized (cleaned and water supply disengaged).	Typically installed with tunnel ventilation. Provides effective cooling in areas with low RH. Tunnel ventilation with cooling pads can lower temperatures inside the barn by 5-10°C.

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[74] Interview with equipment specialist

[75] Tunnel Ventilation of Broiler Houses. 2018. University of Florida Extension. R. A. Bucklin, J. P. Jacob, F. B. Mather, J. D. Leary, and I. A. Naas.

[76] Tunnel Ventilation in Livestock Barns – With and Without Evaporative Cooling. 2018. Ontario Ministry of Agriculture, Food and Rural Affairs.

[77] Ibid.

Technology or Practice	Jurisdictions	Costs	Weaknesses	Strengths
Misting systems	BC - Fraser Valley Ontario Georgia Alabama Texas Florida	High-pressure misting system cost for 100 m length barn is approximately $10,000[78].	More difficult to control relative humidity than with cooling pad systems. Requires maintenance and upkeep of piping and nozzles.	High-pressure misting systems are capable of lowering temperatures by up to 10°C[79]. Can be installed in cross ventilation and tunnel ventilation barns.
Ground Source (Geothermal) Heat Pumps	UK Australia USA - Missouri	Range is between $300,000- $1.8 million. Depends on size of operation and site characteristics (e.g. subsurface characteristics for horizontal or vertical loop installation, electricity system and servicing upgrade requirements, and water supply).	Extensive, and expensive, installation process. May need additional cooling systems in place if required temperature differential cannot be achieved.	Reduced energy consumption and costs (i.e. payback period) estimated 4-5 years.[80] Can be reversed to provide heat in the winter, and cooling in the summer.
Management of stocking densities	Georgia	Migration fencing low cost. Retail costs are approximate $20-$30 per 12-foot lengths. For a 1000 ft (300 m) long barn, with 2 alleys, the cost would be under $1,000.	Flexibility for altering stocking densities is limited in BC and so alternative approaches may need to be found if migration fencing isn't suitable.	Migration fencing is a low-tech and low-cost option. Provides a solution to temperature discrepancies within the barn.
Electrolyte supplement	Adopted by most producers as a tool for flock health	Costs are inexpensive, approximately $10 for 100 g of water-soluble powder. However overall cost will depend on required frequency of use.	Producers should research optimal levels of supplements at various temperatures is needed.	Low tech and simple practice

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[78] Interview with Fraser Valley equipment specialist.
[79] Cooper, O. 2009. Misting system helps combat heat stress in chickens. Farmers Weekly.
[80] Clarke, P. 2015. Ground source heat pumps harnessed for new broiler unit. Farmers Weekly.

3.4 Conclusions and Recommendations for the Poultry Sector

3.4.1 Summary of Fraser Valley Context

The Fraser Valley poultry producers consulted for this report raise layers, broilers, broiler breeders and turkeys and oversee operations of varying sizes within the supply management system. Specific heat management strategies differ depending on the size and type of the poultry operation. Broiler producers are large scale and are primarily using tunnel ventilation, often with cooling pads. Other types of operations (e.g. layer and turkey) are using cross-ventilation and/or mister systems. It is often the flock cycles of July, August and September that are most at risk of being negatively affected by high temperatures.

Many elements of poultry production – such as barn design, flock genetics and feed formulas – are highly technical and carefully managed by producers[81]. However, stakeholders mentioned that flock mortalities due to heat do occur from time to time in the Fraser Valley. As heat events become more extreme and more common, this may necessitate changes to flock management strategies and adoption of new technologies. However, each decision to incorporate new technologies is weighed from a cost-benefit perspective, pointing to the potential value of having more information readily available.

Lessons can be learned from poultry-producing areas that are already warmer than the Fraser Valley. Georgia, Ontario and the UK were the regions that frequently arose in the jurisdictional scan. The literature review and jurisdictional scan of technologies and management practices found that some Fraser Valley producers are already using effective cooling methods. However, there are additional opportunities for continued improvement in heat mitigation that may be effective.

Opportunities for further technology adoption by the Fraser Valley poultry industry include:

- Use of apps to measure the Temperature Humidity Index (THI): Apps are a quick source of feedback for producers to determine temperature and humidity conditions. The use of these apps is not widespread in the Fraser Valley poultry sector and they could be promoted as tools to help inform management actions.
- Exhaust Ventilation and Evaporative Cooling: It is likely that with projected increases in temperatures a broad range of poultry producers will adopt fully enclosed exhaust ventilation systems for increased cooling potential. Most new poultry operations in the Fraser Valley include tunnel ventilation with evaporative cooling systems (e.g. cooling pads or misters) to manage heat. Determining the suitability and cost-benefit of high-pressure misters versus cooling pads for various scales of poultry production and barn designs could help inform producers about cooling options.
- Ground Source Heat Pumps: This technology is beneficial for temperature control and reduces energy costs while addressing heating and cooling needs. However, it is a costly capital investment with a long payback period, and there are no examples of this technology to learn from in the Fraser Valley. As research into these systems continues around the world, more information may become available to Fraser Valley producers and equipment specialists to aid in determining applicability for the Fraser Valley.

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[81] BC Ministry of Agriculture, 2016. Agricultural Building Ventilation Systems. Publication 306-412-1.

3.4.2 Poultry Recommendations

Several opportunities exist to gather more information, undertake knowledge transfer and/or evaluate specific technologies for applicability to the poultry sector in the Fraser Valley. These include:

1. Clarify potential transferability, producer interest and current uptake of heat stress apps. If interest exists, conduct pilots/trials of available heat stress apps (e.g. Thermal Aid) to evaluate their applicability for the Fraser Valley poultry sector.

2. Develop fact sheets and/or case studies regarding:
    - Tunnel ventilation & cooling pads in a new poultry barn install
    - Tunnel ventilation retrofit into existing poultry barns
    - Comparison of evaporative cooling technologies (e.g. misting systems vs. cooling pads)
    - Ground source heat pump feasibility

   These materials would document existing installations and technology applications and include economic information.

3. Develop materials to establish a standard for design (to address the wide range of design variations and resulting quality/performance) and to outline effective operational strategies for improved tunnel ventilation system performance[82]. These materials could consist of fact sheets, maintenance and monitoring checklists, or case studies. Training sessions could be offered for producers on how to effectively operate and maintain their existing systems.

4. Develop fact sheets or other informational materials on best practices for managing the potential negative impacts of increased humidity using high-pressure misting and cooling pads.

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[82] This would assist in implementing recommended actions from the 2016 report: BC Ministry of Agriculture, 2016. *Agricultural Building Ventilation Systems*. Publication 306-412-1.

4.0 Dairy Sector

4.1 Overview of Heat Impacts on the Dairy Sector

The ambient temperature range for optimal dairy cow milk productivity is 0°C to 20°C. At temperatures above 20°C, dairy cows begin to use energy to cool themselves[83]. The main impacts of heat include higher respiration rates, increased sweating and water consumption, reduction in feed intake, reduction of fertility, reduction of butterfat content, and reduction in milk production[84]. Older cows, fresh cows, and calves are most susceptible to heat stress.

As the temperature rises, it becomes increasingly difficult for the animals to dissipate heat. Higher relative humidity (RH) also affects the ability of dairy animals to lose heat via evaporation. The heat stress felt by the animals depends both on temperature and RH, and a temperature-humidity index (THI) has been developed to evaluate dairy herd heat stress. Calculators and charts are available online (Figure 12)[85].

Studies conducted in the 1950s at the University of Missouri indicated an initial stress threshold of a 71 THI. The levels of stress were separated into mild (72 to 79 THI), moderate (80 to 89 THI) and severe (90 THI or greater)[86]. The THI has recently been re-evaluated at the University of Arizona. Dairy herd susceptibility to heat stress is higher today than it was in the 1950s, due primarily to increased milk production and feed intake. Within modern dairy systems, the animals will become heat-stressed starting at an average THI of 68 (Figure 10). At a temperature of 24°C and a relative humidity of 20%, the THI is 68, indicating the beginning of heat stress[87] After four hours in these conditions, feed consumption will be reduced, and respiration rates will increase, reducing rumination.

Over time, the impacts of heat stress can be measured by several indicators, including milk yield production, amount of dry matter (feed) intake (DMI), fertility, and mortalities. A study by the University of Wisconsin-Madison determined that the average lost income due to heat stress can be upwards of several hundred dollars per cow per year[88]. Tools for measuring THI are described in section 4.2.1.

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[83] Dairy Housing - Ventilation Options for Free Stall Barns. 2018. Ontario Ministry of Agriculture, Food and Rural Affairs.

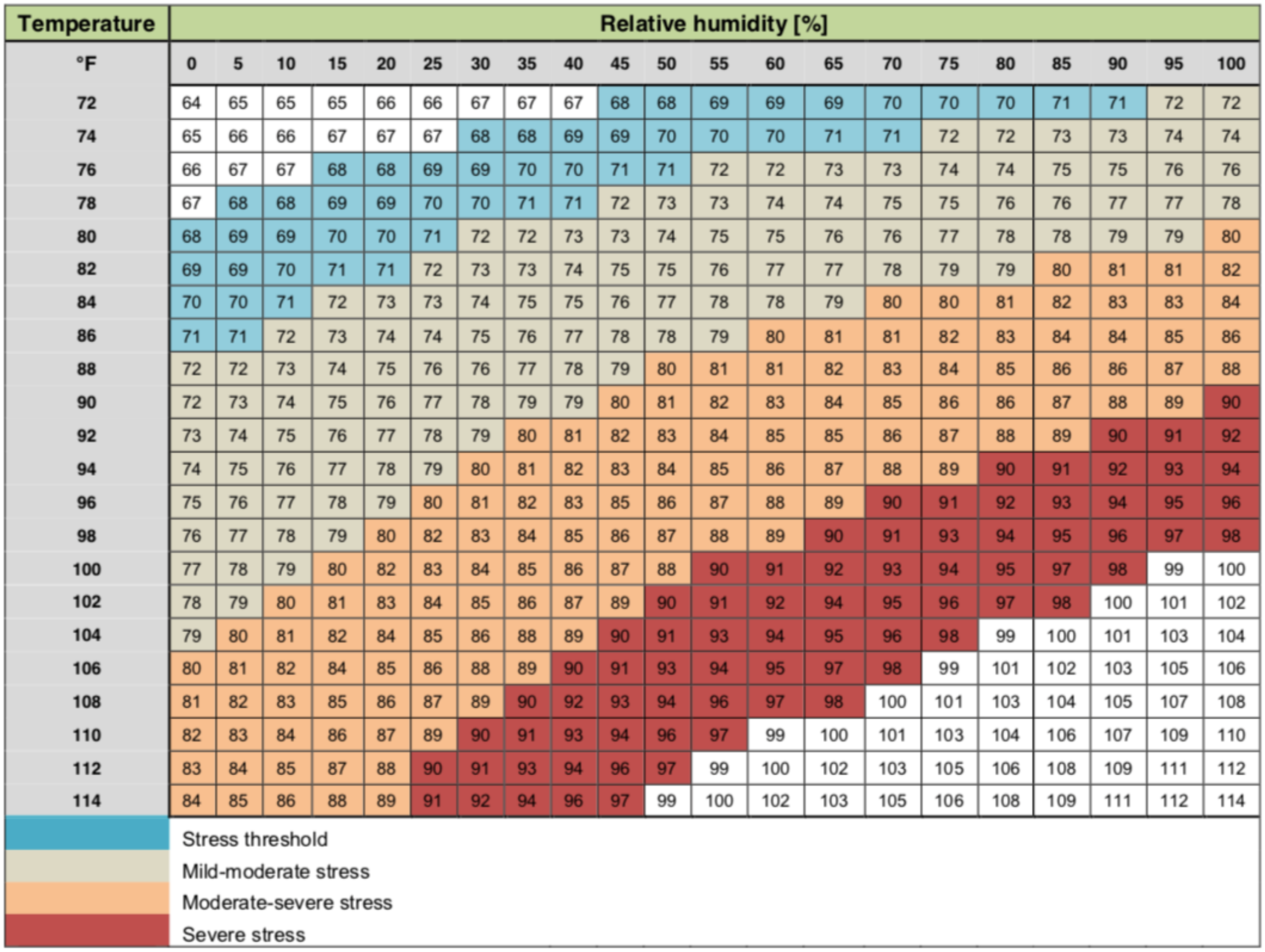
[84] Ontario Ministry of Agriculture, Food and Rural Affairs, 2011. Heat Stress in Dairy Cows, Stress Threshold.

[85] Progressive Dairy, 2014. Calculating the Temperature-Humidity Index (THI).

[86] Dairy Cooling: The Benefits and Strategies. 2015. University of Wisconsin-Madison.

[87] Ibid.

[88] Ibid



Temperature	Relative humidity [%]																				
°F	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
72	64	65	65	65	66	66	67	67	67	68	68	69	69	69	70	70	70	71	71	72	72
74	65	66	66	67	67	67	68	68	69	69	70	70	70	71	71	72	72	73	73	74	74
76	66	67	67	68	68	69	69	70	70	71	71	72	72	73	73	74	74	75	75	76	76
78	67	68	68	69	69	70	70	71	71	72	73	73	74	74	75	75	76	76	77	77	78
80	68	69	69	70	70	71	72	72	73	73	74	75	75	76	76	77	78	78	79	79	80
82	69	69	70	71	71	72	73	73	74	75	75	76	77	77	78	79	79	80	81	81	82
84	70	70	71	72	73	73	74	75	75	76	77	78	78	79	80	80	81	82	83	83	84
86	71	71	72	73	74	74	75	76	77	78	78	79	80	81	81	82	83	84	84	85	86
88	72	72	73	74	75	76	76	77	78	79	80	81	81	82	83	84	85	86	86	87	88
90	72	73	74	75	76	77	78	79	79	80	81	82	83	84	85	86	86	87	88	89	90
92	73	74	75	76	77	78	79	80	81	82	83	84	85	85	86	87	88	89	90	91	92
94	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94
96	75	76	77	78	79	80	81	82	83	85	86	87	88	89	90	91	92	93	94	95	96
98	76	77	78	79	80	82	83	84	85	86	87	88	89	90	91	93	94	95	96	97	98
100	77	78	79	80	82	83	84	85	86	87	88	90	91	92	93	94	95	97	98	99	100
102	78	79	80	81	83	84	85	86	87	89	90	91	92	94	95	96	97	98	100	101	102
104	79	80	81	82	84	85	86	88	89	90	91	93	94	95	96	98	99	100	101	103	104
106	80	81	82	84	85	86	88	89	90	91	93	94	95	97	98	99	101	102	103	105	106
108	81	82	83	85	86	87	89	90	92	93	94	96	97	98	100	101	103	104	105	107	108
110	82	83	84	86	87	89	90	91	93	94	96	97	99	100	101	103	104	106	107	109	110
112	83	84	85	87	88	90	91	93	94	96	97	99	100	102	103	105	106	108	109	111	112
114	84	85	86	88	89	91	92	94	96	97	99	100	102	103	105	106	108	109	111	112	114

🟦 Stress threshold
⬜ Mild-moderate stress
🟧 Moderate-severe stress
🟥 Severe stress

FIGURE 10. TEMPERATURE-HUMIDITY INDEX (THI) FOR DAIRY HERD HEAT STRESS THRESHOLDS[89].

Animal health and productivity impacts due to heat are of concern to dairy operators in the Fraser Valley, and this is evident in the types of technologies that are being incorporated into the design of new barns and in the retrofitting of existing barns. This includes moving away from storing hay aloft, which resulted in insulation and airflow stagnation. New techniques include raising the overall height of the barns for increased airflow and investing in more powerful and larger fans for air circulation. Evaporative and conductive cooling techniques can be used in addition to ventilation. Ventilation and other cooling technologies are further described in sections 4.2.2 to 4.2.5.

In addition to the described impacts on dairy herds, extreme heat can affect forage production associated with dairy operations by reducing yield and crop quality. Production practices to manage the combination of drier and hotter conditions include adding or increasing irrigation, switching to conservation tillage and/or other soil management techniques, and planting new varieties or types of forage crops. These management practices are described in section 4.2.6.

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[89] Dairy Cooling: The Benefits and Strategies. 2015. University of Wisconsin-Madison.

4.2 Dairy Heat Abatement Technologies and Management Practices

The effects of heat stress on dairy herds can be reduced by monitoring temperature and humidity levels, installing correctly designed and operated ventilation systems, and employing effective animal cooling strategies. These approaches are each described in more detail below, along with considerations regarding forage crop management.

4.2.1 Using the Temperature-Humidity Index (THI) as an Indicator of Heat Stress

Measuring dairy herd heat stress can be accomplished at the farm level by attaching monitors to the collars of individual animals, or by installing temperature and humidity sensors (hygrometers) to collect outdoor and indoor climate data. Computers and smart phones can be linked to data sources and systems can be installed to remotely adjust fans, sprinklers, etc., to achieve desired barn conditions[90]. Alternatively, apps can be downloaded onto personal devices that use current and forecasted climate data from nearby weather stations, to calculate the THI.

Apps have been developed that can automatically calculate THI based on local weather station data and/or thermometer-hygrometer readings on the farm. The apps can be used to determine THI without requiring calculations or THI charts. In addition, the apps will automatically classify the degree of heat stress based on the THI value obtained.

The University of Guelph and Ontario Ministry of Agriculture Food and Rural Affairs jointly developed a free app that enables producers to calculate THI by inputting real-time or forecasted temperature and the relative humidity. The app then provides links to management options for reducing heat stress.

Other apps include:

- Thermal Aid: Developed at the University of Missouri (Figure 11)
- Cool Cow: Developed by Purina Animal Nutrition[91]

THI calculation apps have been used by dairy producers in Ontario, Nova Scotia and Israel[92].

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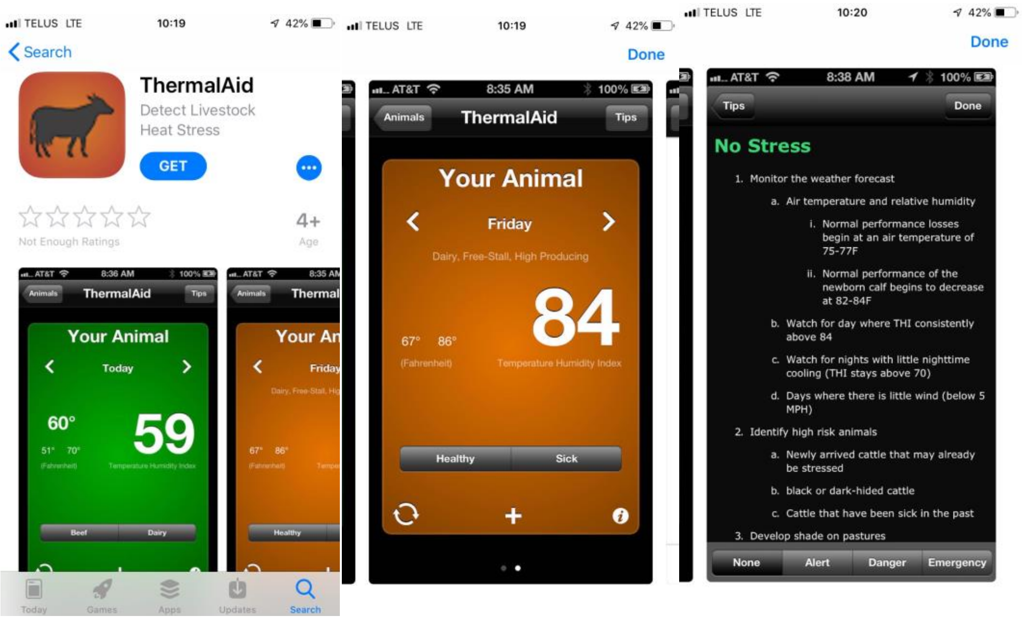
[90] Precision Dairy Farming. University of Kentucky.

[91] Farms.com Farm apps – Purina Cool Cow™

[92] Discussion with Al Dam, OMAFRA Poultry Specialist.



1. Monitor the weather forecast
    a. Air temperature and relative humidity
        i. Normal performance losses begin at an air temperature of 75-77F
        ii. Normal performance of the newborn calf begins to decrease at 82-84F
    b. Watch for day where THI consistently above 84
    c. Watch for nights with little nighttime cooling (THI stays above 70)
    d. Days where there is little wind (below 5 MPH)
2. Identify high risk animals
    a. Newly arrived cattle that may already be stressed
    b. black or dark-hided cattle
    c. Cattle that have been sick in the past
3. Develop shade on pastures

FIGURE 11. THERMAL AID APP DEVELOPED BY THE UNIVERSITY OF MISSOURI.

Current and Future Applicability to Fraser Valley Producers

Anecdotally, dairy producers in the Fraser Valley use a daytime temperature of 25°C as a threshold to warn of impending heat stress within a dairy herd[93]. Producers also indicate that warm nights, when the temperature does not go below 12-15°C, compound heat stress impacts as livestock do not have the opportunity to cool down overnight[94]. Many producers use climate sensors coupled with automated ventilation system components (such as fans). However, referencing THI data and THI reference tools (e.g. charts and heat stress apps) does not appear to be common practice.

4.2.2 Ventilation

Older "drive-through" barns do not maximize airflow, and the storage of hay above cows further reduces air movement. As a result, all new barns are being built to maximize airflow. Air circulation within a barn is important to reduce stratification of air temperatures and improve the effectiveness of evaporative cooling over the animals. Barn ventilation is critical to airflow and barns. In most cases, the maximum allowable ventilation rate is based on several factors, including[95]:

i) minimum target of 1,000 cubic feet per minute (CFM) (28 m^3/minute) per animal;
ii) minimum target of 1 full air change per minute during summer months;
iii) maximum target air velocities of 2 – 3 m/s within the barn.

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[93] DeJong. J. Dairy farmer. Personal communication
[94] Ibid.
[95] BC Ministry of Agriculture, 2016. Agricultural Building Ventilation Systems. Publication 306-412-1.

Dairy herd heat management strategies that improve air circulation can be considered during new barn construction and during the retrofitting of existing barns, parlours and robot installations. The three types of ventilation systems most commonly used in the dairy sector are[96]:

- Natural ventilation
- Circulation fans
- Exhaust (tunnel or cross-flow) ventilation

Each system is described below, followed by a summary of findings from the literature review and jurisdictional scan, and a discussion regarding the applicability to the Fraser Valley dairy sector.

Natural Ventilation

Natural ventilation systems use large side wall openings (or in larger barns, end wall openings) to allow fresh air to flow in and out (Figure 12). These openings are fitted with either a plastic curtain or a moveable insulated wall that can be adjusted incrementally to a more open or closed position to control the overall flow of air. Chimneys or vent openings along the roof peak are also incorporated, both of which may have adjustable baffles to control the airflow rates. The curtains on side walls and end walls can be closed completely during cold or inclement weather to protect the animals.

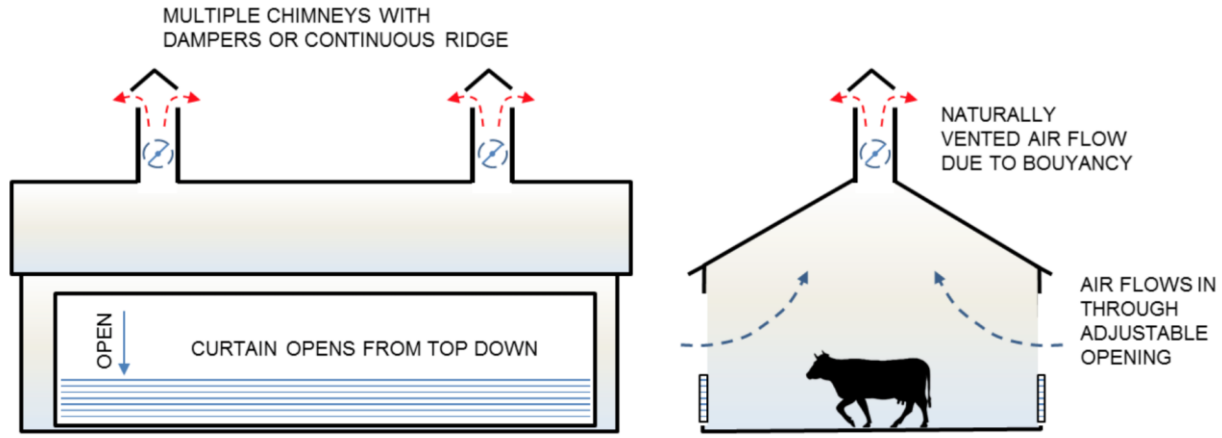

FIGURE 12. NATURAL VENTILATION SYSTEM INDICATING SIDE WALL CURTAINS AND CHIMNEYS IN A DAIRY BARN.

Natural ventilation systems are designed to maximize airflow in the summer to provide cooling. Farm site layout is key to effective design, and when a new barn is being constructed it is important to consider the direction of prevailing winds.[97] Large adjustable side wall inlets make use of prevailing winds and barns are often designed with a minimum height of 4 m and as high as 5 m.

Natural ventilation systems have relatively low capital and operating costs, are quiet and have limited reliance on electricity. Substantial airflow rates are possible, especially for barns situated to take advantage of prevailing wind conditions.

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[96] Ibid.

[97] Dairy Housing - Ventilation Options for Free Stall Barns. 2018. Ontario Ministry of Agriculture, Food and Rural Affairs.

Circulation Fans

Many dairy producers choose to increase airflow by adding circulation fans to their barns. Fans can be located within the chimney and/or mounted to walls and may be variable speed or single speed. As temperatures increase in the barn, an automated controller will allow variable speed fans to increase, and/or the fan angle can be changed to direct air into specific areas of the barn. Fans located close to the fresh air supply will promote faster distribution and mixing of air.

Fans must be selected based on their capacity and the air velocity they are able produce[98]. Each barn will have unique fan specification needs, but the air speed at the animal level generally ranges from 0.25 – 0.50 m/s. Many producers have installed automated control systems that will turn fans on when the barn temperature reaches 21°C and all fans should be running when the barn temperature reaches 27°C.

Although Variable Speed Drives (VSDs) are not a heat abatement technology, they can save energy and reduce wear and tear on equipment. VSDs adjust the motor input frequency and voltage of electric engines to achieve the optimal speed to suit temperature conditions[99]. VSDs save energy by running at lower speeds whenever possible and place less stress on the motor during start up resulting in less mechanical wear[100]. VSD costs vary widely depending on the size and scale of the requirement. However, this technology is proven to save energy, and therefore energy-related costs, over time. Furthermore, businesses may be eligible for discounts from BC Hydro when installing VSD fans[101].

High Volume Low Speed (HVLS) fans are large (1.8 – 7.3 m in diameter) and are capable of moving 400,000 CFM (Figure 13). They are designed to be quieter than high-speed circulation fans or exhaust fans. HVLS fans have been shown to reduce the temperatures inside dairy barns between 6-8ºC[102]. Horizontal axial circulation fans are typically axial-type fans constructed of aluminum, galvanized or fibre-reinforced plastic. They can either be fully open or be enveloped by a basket screen for safety protection. Horizontal fans range in size from 0.5 m up to 1.8 m in diameter (Figure 13).

FIGURE 13. HIGH VOLUME LOW SPEED FANS (LEFT) AND HORIZONTAL FANS (RIGHT).

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[98] Choose fans that will provide at least 500 CFM/cow, up to 1,000 CFM/cow and air velocities in the range of 220-500 FPM (2.5-5.5 mph). During hot weather, the air-exchange rate should be a minimum of 1,000 CFM per cow. An air velocity of 400 to 600 fpm has been shown to reduce heat stress and is often used as a design specification.

[99] Farm Energy IQ – Dairy Farm Energy Efficiency. Gary Musgrave, Penn State Extension.

[100] Dairy Cooling: The Benefits and Strategies. 2015. University of Wisconsin-Madison.

[101] BC Hydro. Business: Energy efficient technologies. Optimizing fan and pump systems. Accessed Feb 2019.

[102] Sun North Systems Ltd. Agricultural Ventilation Systems.

Exhaust Ventilation (Tunnel and Cross-Flow Ventilation)

The use of exhaust fans in dairy barns is commonly referred to as tunnel ventilation or cross ventilation, depending on the configuration of the airflow system. With a tunnel ventilation system, large fans (diameter of 1.2 - 1.8 m) installed horizontally along an end wall, are used to move air through a barn at an air speed fast enough to provide convective cooling of the herd. Air enters the barn at one end and is expelled at the other. Since the air speed depends on the width of the barn, long, narrow barns ventilate more efficiently than short wide ones. In theory, to create the desired 'wind-chill effect', all wall openings should be closed between the exhaust fans at one end of the barn and the end wall openings at the other. In practice, opening the curtain slightly (about 5 cm (2 in.)) from the bottom provides some fresh air along outside rows of stalls[103].

High air speed at animal level is essential in hot climates, especially with high humidity levels. The temperature inside a tunnel-ventilated barns can be as much as 8^{o}C cooler than the outdoor temperature However, when humidity is above 90% that difference drops to 3-4^{o}C[104]. Tunnel ventilation is only needed during high temperatures. Some tunnel ventilation fans are available with two-speed motors which may help with air distribution in the barn during cooler weather[105].

Cross-flow ventilation is similar to tunnel ventilation except the air intakes are located along the width of one barn wall with fans located along the opposite side wall (Figure 14). This creates a wind-chill effect across the width of the barn. Baffles may be installed in the barn to further increase air flow[106].

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[103] Dairy Housing - Ventilation Options for Free Stall Barns. 2018. Ontario Ministry of Agriculture, Food and Rural Affairs.

[104] Tunnel Ventilation, so far, so good. 2011. Dairy Herd Management.

[105] Ibid.

[106] Cross-Ventilated Barns for Dairy Cows: New Building Design with Cow Comfort in Mind. 2013. Extension.

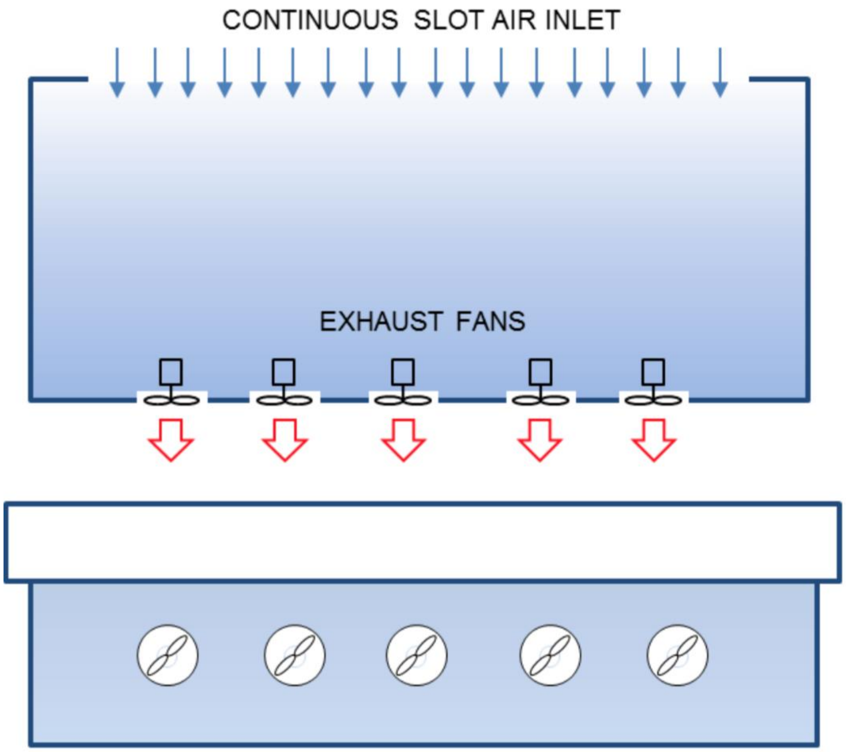

FIGURE 14. CROSS-VENTILATION SYSTEM: AERIAL VIEW (TOP) AND SIDE VIEW (BOTTOM).

The main advantages of exhaust ventilation systems (i.e. tunnel ventilation and cross-flow ventilation) over natural ventilation is that there is better control over the temperature and humidity of the barn environment, the barn can be oriented however desired and there is reduced fly pressure in summer[107]. The disadvantages include high equipment, installation and energy costs, increased knowledge and training to ensure efficient performance and adequate maintenance of systems.

While exhaust ventilation is rare in the BC dairy industry, it is common in other regions. Cross ventilation has become the preferred system in newly constructed barns housing large herds in Wisconsin[108]. Dairy producers in hot and humid locations, such as Florida and Texas, commonly use tunnel ventilation[109]. However, high humidity conditions, such as those found in Florida, can present a challenge because tunnel-ventilated barns with evaporative-cooling systems (e.g. sprinklers or foggers) lose much of their efficiency when the humidity gets above 90%. Therefore, ambient air conditions outside the barn must be balanced with those inside the barn.

In a 2006 study, Mississippi State University researchers found that cows cooled by tunnel ventilation ate 12% more feed per cow per day and produced an average of 2.6 kg more milk per cow per day in the summertime heat than cows cooled with shade and fans alone[110]. The tunnel-ventilated cows also had

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[107] Tunnel Ventilation, so far, so good. 2011. Dairy Herd Management.

[108] Dairy Cooling: The Benefits and Strategies. 2015. University of Wisconsin-Madison.

[109] Tunnel Ventilation, so far, so good. 2011. Dairy Herd Management.

[110] Smith, T.R., Chapa, A., Willard, S., and B. Herndon. 2006. Evaporative tunnel cooling of dairy cows in the Southeast. II: Impact on Lactation Performance. Journal of Dairy Science 89(10): 3915-23.

lower peak body temperatures and slower respiration rates. This was followed up by another 2006 study in Mississippi to evaluate the potential of tunnel ventilation combined with evaporative cooling (e.g. misting) to alleviate heat stress in dairy barns. This combined approach further reduced heat stress and respiration rates, and reduced body temperatures by an average of 0.6ºC compared with natural ventilation and circulation fans[111].

A 2008 review of various cooling systems conducted by Cornell University examined the costs associated with fan purchasing and installation[112]. While the specific costs of this analysis are too out of date to be relevant, it is worth noting that the tunnel fans costs are nearly three times the cost of cooling fans for the same size of barn. A more recent American study on cost modeling for dairy farm design concluded that, on average, exhaust ventilation cost twice as much to operate as natural ventilation systems, and operating costs in hotter climates were approximately double those in milder climates[113].

Current and Future Applicability to Fraser Valley Producers

In B.C., the predominant ventilation system used in all types of dairy barns (e.g. calf barns, heifer/dry cow barns and milking barns) is natural ventilation with circulation fans. Very few dairy operators in the Fraser Valley (if any) are using exhaust ventilation systems (tunnel ventilation or cross ventilation). However, one dairy operator based in the Okanagan indicated that some new dairy barns in that region are being built with exhaust systems to better handle extreme heat in the summer. Exhaust ventilation systems may gain more attention in the Fraser Valley as summer temperatures increase[114].

4.2.3 Evaporative and Conductive Cooling

The main methods of using water for cooling in dairy barns include evaporative cooling (e.g. sprinklers, misters) and conductive cooling (e.g. below-stall in-ground cooling or cooling mattresses). These technologies are described in detail below.

Sprinklers

Sprinklers can be used to cool the animals through evaporation. When water hits the animal, their body heat combined with air circulation (from natural ventilation, fan circulation, or exhaust systems) causes the water to evaporation, removing heat energy. (Figure 15). It is critical that a sprinkling period is followed by a non-sprinkling period to allow this evaporation to occur. Automated systems can link sprinklers to barn temperatures and typically include an adjustable timer to ensure the sprinklers operate for a limited time period. Sprinklers are typically activated at temperatures over 21ºC, with increasing frequency as the temperature rises[115].

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[111] Smith, T.R., Chapa, A., Willard, S., and B. Herndon. 2006. Evaporative tunnel cooling of dairy cows in the Southeast. I: Effect on Body Temperature and Respiration Rate. Journal of Dairy Science 89(10): 3904-14.

[112] Gooch, C. 2008. Dairy freestall barn design – a Northeast perspective. Biological and Environmental Engineering, Cornell University.

[113] Mondaca, M.R. and N.B. Cook, 2019. Modeled construction and operating costs of different ventilation systems for lactating dairy cows. Journal of Dairy Science. 102(1): 896-908.

[114] Ventilation of the Milking Complex. 2015. BC Ministry of Agriculture.

[115] Dairy Housing - Ventilation Options for Free Stall Barns. 2018. Ontario Ministry of Agriculture, Food and Rural Affairs.

As opposed to misters, the droplet size associated with sprinklers is large enough to wet the skin surface[116]. Low-pressure (20 - 40 psi) sprinklers produce large droplets that can penetrate the hair coat more effectively than mist[117]. Water lines must be appropriately sized and sprinklers must be located at suitable intervals to provide adequate water flow for uniform distribution along a supply pipe or across a holding area.

Because the application of water will increase the humidity, it is important to maintain high levels of air exchange in areas with these systems[118]. Sprinkler systems must be oriented to avoid bedding and/or feed. They are typically applied at exit areas (parlour, alley, platform), along feed lines, or in holding pens. A low-pressure evaporative cooling system for an average sized barn costs around $5,000 to install[119].

FIGURE 15. A SPRINKLER OPERATING IN A DAIRY BARN IN MAINE, USA[120].

Misters

High pressure misters (about 1,000 psi), sometimes referred to as fogging systems, produce very small droplets in front of fans or other air inlets. Fans must be incorporated into the design to effectively move and evaporate the water droplets (Figure 16). Since most barns have a water supply system that operates at or near 50 psi, a booster pump is required. High pressure nozzles can be attached to fans that direct the mist above animal feeding and traffic areas. In order to minimize plugging, in-line filters can be used. As with sprinklers, fogging systems can be automated so sprinklers are triggered at a specified temperature and for limited time intervals.

The cooling effect these systems can provide is limited by the quantity of water that can evaporate into the incoming air before the air is saturated. Therefore, the lower the humidity of the incoming air, the more water can be added into it and the greater the cooling potential, making evaporative cooling particularly effective in arid climates. For example, assuming 75% evaporation efficiency, air entering at a temperature of 32^{o}C and 30% RH undergoes a temperature reduction of approximately 10^{o}C and a THI reduction of

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[116] Dairy Housing - Ventilation Options for Free Stall Barns. 2018. Ontario Ministry of Agriculture, Food and Rural Affairs.

[117] Dairy Cooling: The Benefits and Strategies. 2015. University of Wisconsin-Madison.

[118] Dairy Cooling: The Benefits and Strategies. 2015. University of Wisconsin-Madison.

[119] Interview with Fraser Valley equipment specialists.

[120] Maine Public Radio, 2018. As milk production cools in summer, farmers try to help cows take the heat.

approximately 6.3 units[121]. However, entering air at 32°C and 70% RH undergoes a temperature reduction of approximately 3°C and a THI reduction of only about 2.6 units. Evaporative cooling can also be effective in humid climates during the hottest part of the day, which is when air humidity is lowest[122].

Fogging systems increase the RH in the barn, which must be monitored to avoid condensation and water dripping in areas of the barn. Maintenance of high-pressure nozzles and hoses is critical for the misting to operate efficiently. If the pressure is too low then the droplets will be too large, and the mist may not evaporate before it reaches the ground, which can lead to wetting of bedding and/or feed.

Costs for installing high-pressure misting systems within an average dairy barn are a minimum of $10,000[123].

FIGURE 16. HIGH PRESSURE MISTING ATTACHED TO FANS[124].

Cooling in Stalls

Conductive cooling technologies, such as waterbeds, can be used under bedding to remove excess heat from cattle,[125,126]. A thin rubber layer over the top of the water-based mattress draws the heat away from the animal's body. While some products are commercially available, there is still technology development and demonstration underway[127,128]. Another method of conductive cooling involves the installation of piping under the bedding area that circulates cold water. Heat is transferred from the animal to the cooler water, which is being pumped from groundwater, or another chilled water source.

While evaporative cooling (using sprinklers and misters) is particularly effective in areas with low humidity (such as dairy producing regions of California and Arizona), in regions with high humidity, such as Ontario, Georgia, Florida, and Mississippi, conductive cooling (cooling pads) may be more suitable. Conductive cooling is also being used in France. Research into evaporative and conductive cooling is occurring at several

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[121] BC Ministry of Agriculture, 2016. Agricultural Building Ventilation Systems. Publication 306-412-1
[122] Dairy Cooling: The Benefits and Strategies. 2015. University of Wisconsin-Madison.
[123] Interview with Fraser Valley equipment specialists.
[124] Artex Barn Solutions, equipment specialists based in Abbotsford, BC.
[125] Conductive cooling: Could it be the new cow comfort concept? 2014. Progressive Dairyman.
[126] Dairy Cooling: The Benefits and Strategies. 2015. University of Wisconsin-Madison.
[127] Water bedding solutions: an innovative tool to combat heat stress. 2017. International Dairy Topics, Pauline Guéganno.
[128] Bioret-Agri. Coolant Recirculating Waterbed.

universities in the United States, including Kansas State University, Cornell University, and the University of California, Davis.

In California, a conductive cooling system is being developed that circulates cool water through heat exchanger mats installed below the surface of freestall beds[129,130.] The research indicates that the system has the potential to significantly reduce the amount of energy and water required to protect the animals from heat stress and that conductive cooling is particularly effective under humid conditions[131]. To reduce energy consumption, water flowing through the mats is recirculated and cooled through an evaporative chiller called a Sub-Wet Bulb Evaporative Chiller. In addition, convection cooling is being tested, using fabric ducting to direct cool air onto the cows while they lie down and when they eat. The air is cooled using a high-efficiency direct evaporative cooler.

Similar research at Cornell University indicates that conductive cooling effectively mitigates heat stress in dairy herds[132]. Results indicate that when the animals were conductively cooled with 4.4^{o}C water, body temperature decreased, respiration rate decreased by 18 breaths per minute, milk yield increased by 5% and dry matter intake increased by 14% compared to control animals. Waterbeds placed directly on concrete, with no insulating layer, had no detectable impact on heat stress, indicating that the cooler temperatures found in concrete alone cannot generate a conductive cooling effect.

A company in France, BioRet Agri, produces water mattresses called AquaClim. When a cow lies down on the waterbed its heat is transferred to the water, which can then be cooled again through geothermal exchange and recirculated to provide continual cooling[133].

Current and Future Applicability to Fraser Valley Producers

Low-pressure in-barn sprinkler systems are used in some Fraser Valley dairy barns. There appears to be minimal adoption of evaporative cooling and as noted above, conductive cooling is only used in a small number of jurisdictions (and most approaches are still being tested)[134]. Equipment installers in the Fraser Valley have noted that some low-pressure sprinkler systems in barns are not functioning properly. Standardized information on installation and maintenance of evaporative cooling systems may be a useful resource for dairy producers. Some producers are hesitant to install misting or sprinkler systems because they are concerned that added humidity may create animal health issues. However, as summer temperatures increase, these systems may become more effective.

As temperatures continue to rise it is likely that cooling systems will be needed for the periods of the summer when temperatures remain high and/or spike[135]. Considerations for producers include costs of additional equipment (e.g. sprinklers, fans, conductive cooling pads), water consumption and level of operation/maintenance required. Producers in the Fraser Valley have expressed concerns over adding

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[129] Conductive Cooling System for Dairy Farms. 2014. Southern California Edison.

[130] Keeping Cows Cool with less water and energy. 2017. UC Davis.

[131] Ibid.

[132] Gebremedhin, K.G., Wu, B. and K. Perano. 2016. Modeling conductive cooling for thermally stressed dairy cows. Journal of Thermal Biology. 56:91-9.

[133] BioRet Agri, 2019. Main website.

[134] BC Ministry of Agriculture, 2016. Agricultural Building Ventilation Systems. Publication 306-412-1.

[135] Polsky, L., & von Keyserlingk, M. A. (2017). Invited review: Effects of heat stress on dairy cattle welfare. *Journal of dairy science*, *100*(11), 8645-8657.

water to barn systems as this will increase RH inside the barn. However, evaporative cooling has been used successfully in the dairy industry in high-humidity climates, such as Florida. Proper operation and management of evaporative cooling systems is required to ensure water introduced into the barn does not significantly raise RH levels. In the Fraser Valley, when temperatures reach over 20°C, RH levels tend to range from 40-70%[136]. During these conditions, if evaporative cooling is used, producers will have to manage humidity levels using THI calculations to ensure heat stress of animals is kept to a minimum as much as possible. Future research should include identifying management practices for evaporative cooling systems that are used in other high-humidity climates, and applicability of specific practices and systems to the Fraser Valley Context.

4.2.4 Radiant Barriers

Radiant barriers work by reducing the warming effects of the sun, and heat transfer, through the reflection of thermal radiation. Solar energy heats the outside of the roof and the sheathing in the roof by conduction, causing the underside of the roof to radiate heat down into the barn. A radiant barrier prevents the solar heat from being transferred into the upper barn space through a reflective, low emissivity surface. This barrier is placed on the underside of the roof[137] and can be installed in new barns or retrofit into older barns (Figure 17). There are several different types of radiant barriers including thin radiant barrier foils, foil-faced bubble wrap or roof sheathing panels. The amount of heat radiated depends on the surface temperature and the emissivity of the material[138]. Radiant barriers that record the highest efficacy are those which consist of a roof sheathing panel with heat-reflective film laminated to one side[139].

In order for radiant barriers to work, the attic (or upper ceiling area) of the barn must be well ventilated. If radiant barriers are installed on top of other materials, they will simply conduct heat through these building materials. Therefore, the barriers should be installed with the reflective surface facing into the attic adjacent to ventilated air space. Dust accumulation on the surface will reduce its capability and therefore should be minimized.

A study using reflective material on calf hutches found that the internal hutch temperatures of the reflective covered hutches was 2.0-2.5°C cooler than control hutches during the hottest 4-hour portion of the day[140]. The temperature in a 70,000 ft^2 dairy barn in Saskatchewan was 39°C before installation and reduced to 22°C after the radiant barrier material was installed[141].

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[136] Generalized from data of Brander Road weather station from PICS interactive map and database website.

[137] Radiant Barriers. U.S. Department of Energy.

[138] Amvic Systems building equipment dealers, based in Toronto, Ontario.

[139] Ibid.

[140] Haberman, J. A. (2015). *Biological Effects of Hutch Covers in Reducing Heat and Cold Stress in Individually Housed Dairy Calves* (Doctoral dissertation).

[141] Discussion with radiant barrier supplier.

FIGURE 17. INSTALLATION OF RADIANT BARRIER MATERIAL ON A BARN ROOF.

Costs for installation vary greatly depending on the characteristics of the barn and roof design, and while the material itself may be relatively inexpensive (less than $20 per m^2)[142], extensive labour is typically required. A Fraser Valley dairy producer interviewed for this report replaced a roof on a 25,000 ft^2 (2,322 m^2) barn and added a radiant barrier at the same time for an additional cost of approximately $30,000. Installation costs for new barns are much less than installing material on an existing barn roof (approximately $3/ft^2 for a new build vs. $5/ft^2 for a retrofit). Costs associated with installation in new barns are therefore much less than those associated with installing material on an existing barn roof.

Radiant barriers have a proven track record in the residential construction market and in the agricultural sector. While the jurisdictional scan did not find that particular areas stood out for adoption of this technology, the equipment specialists interviewed for this report, and nearly all equipment retailer websites, noted that agriculture is a key component of their business. This indicates that this technology is likely fairly widespread.

Current and Future Applicability to Fraser Valley Producers

Radiant barriers have already been installed in some Fraser Valley dairy barns. Because it's more cost effective to install a radiant barrier when a new barn or a new roof is being built, rather than retrofitting an existing barn, there is likely to be more adoption over time (with roof replacements and/or new barn construction).

4.2.5 Breeding Initiatives

Breeding initiatives for cattle heat tolerance are occurring in a few jurisdictions, with notable examples in Australia and Florida. Researchers at the University of Florida are working to breed increased heat tolerance into cattle by developing a dominant trait for the "slick" mutation that results in a short, sleek hair coat. The sleek coat allows for greater evaporative cooling, thereby reducing overall body temperature

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[142] TekFoil reflective foil insulation. Cost sheets.

at a faster rate. Currently, there are two University of Florida-bred bulls offered to dairy producers interested in incorporating slick hair coats into their breeding programs. The university is working to develop bulls that will produce 100% short-haired progeny[143].

In Australia, the School of Applied Systems Biology at La Trobe University, is at the forefront of genetic research for heat tolerance within the dairy industry[144]. The research at La Trobe has indicated that heat tolerance has been favourably linked with fertility and unfavourably with production; which means that a strong focus on heat tolerance in bulls may improve fertility but compromise production. A greater focus on genetic research on female cattle has been proven to be effective at influencing milk production rates under heat stress.

DataGene, an industry-owned organization in Australia, has released Heat Tolerance Australian Breeding Values (ABV), which are considered a world-first[145] and identify gene markers for heat tolerance. The Heat Tolerance ABV will allow producers to identify animals with greater ability to tolerate hot weather with less impact on milk production. The reliability of the Heat Tolerance ABV is 38% but reliability is expected to improve, as more data becomes available.

Current and Future Applicability to Fraser Valley Producers

Fraser Valley producers indicated interest in learning about breeding initiatives to develop heat tolerant herds. Genetic breeding for heat tolerance is in a nascent stage, but it will be worthwhile to track breeding research developments and successes over time so that opportunities for adoption in the Fraser Valley can be better understood.

4.2.6 Management of Forage Crops

There are a number of considerations regarding best management practices for forage crops within the context of heat management. These include best practices for irrigation, soil management, and crop selection. Irrigation influences crop quality and crop yield, and while some Fraser Valley dairy producers have been able to rely on precipitation, hotter and drier summers are likely to result in greater reliance on irrigation. Irrigation systems are costly, and some producers may be required to obtain water supply licensing. Sector-wide, increasing irrigation requirements will also increase pressure on local water resources.

In addition to irrigation best practices, soil management for water retention is also critical. This includes ensuring that soil organic matter content and soil structure is maintained and improved over time. Examples of potential soil management best practices include: planting cover crops during the winter to minimize wind and water erosion, strip cropping for growing two or more crops across a field wide enough for independent cultivation, no-till or low-till field management, and the regular addition of compost and other organic matter sources[146].

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[143] Dairy Update, Quarterly Newsletter. 2018. University of Florida.

[144] Duckworth, B. 2018. Genetic research speeds pace of dairy breeding. The Western Producer. August 9, 2018.

[145] Rural News Group, 2018. Breeding for heat tolerance. Dairy News: The Rural News Group, New Zealand.

[146] BC Ministry of Agriculture. 2010. British Columbia Environmental Farm Plan Reference Guide 4th Edition - (includes major revisions from 3rd Edition, March 2005). Publication 978-0-9738261-2-8.

Crop species and variety selection will also play a role in the amount of water required over the growing season. Changes to cropping programs may also assist in getting the most yields possible from limited water[147].

A recent report by the Pacific Field Corn Association for the BC Climate Action Initiative indicated that anticipated changes in climate may impact forage production in the Fraser Valley through increased erosion risk, delays in spring planting, and potential for lower yields due to a shorter growing season with more prolonged hot and dry periods[148]. The project tested and demonstrated corn hybrids suited to both late planting and/or early harvesting that are heat and flood tolerant. This study evaluated grass response to two limiting factors: irrigation and nitrogen (N). In two of three years, there was a very significant response to irrigation increasing yield; in 2015 and 2017 N increased yield by about 1 tonne per hectare with no irrigation but irrigation plus the same amount of N increased yield by 3-5 tonnes per hectare.

Research by the Pacific Field Corn Association in Agassiz indicated annual yield increases of 13-35% from irrigation for different grass species and varieties[149]. Yield increases ranged from about 13-29% for three orchard grass varieties and 17-35% for four perennial ryegrass varieties. The project developed a compliment of strategies to enable farmers to adapt to warmer summers all the while improving their yield and feed quality profile. The overall strategy is based on optimizing a balance of summer annual, winter annual (cover crops) and perennial crops to maximize use of seasonal growing degree days and moisture patterns.

Current and Future Applicability to Fraser Valley Producers

In recent history, many Fraser Valley dairy producers have not irrigated their forage crops. While some producers – particularly those with sandy soils – have had irrigation in place for a number of years, recent hot and dry summers have resulted in a growing number of producers considering irrigation for forage crops where irrigation was previously not required. Presently, the forage harvests most impacted by hotter and drier weather are in the late summer and fall.

Irrigation systems represent a large capital investment for Fraser Valley dairy operations, which typically grow much of their own forage. The decision to purchase and install an irrigation system requires careful consideration of costs and benefits[150]. Anecdotally, the amount of irrigation activity has increased substantially since 2010 in the Fraser Valley. Growth in sales of irrigation equipment as well as the digging of new wells are both indicators of this trend. Some operators may use the same irrigation equipment on several parcels, moving it from one location to another, rather than purchasing equipment for each parcel[151].

An important consideration regarding new irrigation requirements is the new water licensing requirements. Municipal water may be used for livestock watering but is not commonly used for irrigation. Therefore, any new irrigation source would likely be groundwater, or pumped/diverted surface water from the Fraser River

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[147] BC Ministry of Agriculture, 2015. Drought management factsheet: Alternate forage crops when irrigation water is limited. Order No. 665.000-6.

[148] The Pacific Field Corn Association, 2018. Strategies to Improve Forage Yield and Quality While Adapting to Climate Change. BC Agriculture & Food Climate Action Initiative.

[149] Ibid.

[150] Interviews with consultants and equipment specialists.

[151] Interview with irrigation consultant.

or from other watercourses. It is possible that some operators in the Fraser Valley who decide that they require irrigation may encounter difficulties with access to licensing or necessary supply infrastructure.

4.3 Summary of Technologies and Management Practices for the Dairy Sector

Technology	Where It Is Used	Costs	Weaknesses	Strengths
Automated Climate Controls and Apps	BC – Fraser Valley, many in the dairy sector use automated barn climate controls Apps developed and used in Ontario[152],Missouri, Nova Scotia and Israel	Cost of automation depends on size of the barn, but average cost is approximately $10,000. Apps are free or very low cost.	Automated systems and apps are only as efficient and accurate as the data that they are using. Data from farm weather stations or from cattle collars are best. Requires WIFI connectivity.	Allows for real time and precision management of barn conditions. Provides quick feedback on barn conditions and management actions to reduce heat stress. Can be used immediately.
Natural Ventilation	Quebec Ontario BC - Fraser Valley and Vancouver Island	Specific costs for curtains are difficult to ascertain. At least 8 types of curtains are used in dairy barn design. Information available via equipment dealers	May not be able to provide adequate cooling in future without additional mechanical or exhaust-based air circulation for ventilation.	Least expensive form of ventilation. Least ongoing management and maintenance required compared to exhaust ventilation systems.
Circulation Fans	Most barns with natural ventilation also include circulation fans	On average at least $1,000 and upwards of $6,000 per fan for equipment and installation. Axial fans are less expensive than HVLS fans.	Requires multiple fans. Energy costs associated with operating the fans may be high.	Effective movement of air. Can be connected to evaporative cooling technology, such as misters. Can be controlled from a remote source if part of an automated system.
Exhaust Ventilation system	Florida Texas Ontario[153] BC - Okanagan Wisconsin Mississippi	Specific costs for exhaust ventilation systems are difficult to estimate and will depend on the size of the barn and whether the fans are being installed for tunnel or cross-ventilation.	May be more suitable to large barns. Requires high levels of energy.	Very effective at cooling the barn and can be automated. The temperature inside the tunnel barns can be as much as 15°C cooler than the outdoor temperature[154].

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[152] Heat Stress in Livestock and Poultry App. Ontario Ministry of Agriculture Food and Rural Affairs.

[153] Kie Farms Ltd., St. Mary's, Ontario. DSL Structures.

[154] Tunnel Ventilation, so far, so good. 2011. Dairy Herd Management.

Technology	Where It Is Used	Costs	Weaknesses	Strengths
Low-pressure sprinkling	Wisconsin Florida Missouri California Arizona Kansas BC - Fraser Valley Ontario	Sprinkler system costs approximately $5,000 for equipment and installation in average dairy barn[155]; this does not include the additional cost of water.	Need to be careful about moisture-related bacteria growth/animal health impacts. May not be as effective at lowering barn temperatures in regions with high humidity.	Effective at lowering cow body temperature. Can be installed in one area of the barn or in the milking parlour.
High-pressure misting	BC - Okanagan and Interior Wisconsin Florida Missouri California Arizona Kansas	The equipment (e.g. piping) can cost approximately $20 per linear foot. For a 250 ft long barn with 2 alleys (or 500 ft of length total), the cost would be approximately $10,000 (for typical barn in the Fraser Valley).	Possible for negative impacts to herd health if the relative humidity stays high for a prolonged period of time. May not be as effective at lowering barn temperatures in regions with high humidity.	High-pressure misting can reduce average barn temperatures by around 5°C[156]. May add moisture to feed on hot days, improving the amount of water that the cattle receive.
Conductive cooling systems – cooling pads	Kansas California Arizona France	Not available at this time. May require water system retrofit and energy for chilling water.	Most examples found in the literature are still under development. Requires water source and may require energy for cooling the water.	Benefits the animal directly (cooling not directed to ambient air). May reduce both energy costs and water consumption. Effectiveness is not as dependent on RH as evaporative cooling techniques.

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[155] Interview with Fraser Valley equipment specialist.

[156] Dairy ventilation solutions for high scale milk production. Munters

Technology	Where It Is Used	Costs	Weaknesses	Strengths
Radiant Barrier Insulation	Commonly used in building construction in residential and agricultural sectors throughout North America and Europe.	Cost of material is under \$1.00 per ft^2 and installation costs ranges from \$3-\$5 per ft^2 [157,158]. It costs approximately \$30,000 for installation in a 25,000 ft^2 new roof for a barn housing approximately 150 cows[159].	Can be expensive if installing as a retrofit. Requires adequate ventilation throughout the barn to work effectively.	Low maintenance once installed. High cooling potential. Can be installed during a new build or during a retrofit.
Forage crop management	BC – all regions Saskatchewan Alberta	Irrigation equipment and installation can be at least \$1,000 per acre for a dairy operation.	Irrigation requires costly equipment, source of water and possibly water licensing. Soil management and crop planning may require additional labour.	Reliable crop yields during hot and dry conditions. Extends the growing season. Better quality forage crops for feed

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[157] Discussion with radiant barrier supplier.
[158] Prices from Innovative Insulation supplier.
[159] DeJong, J, personal communication regarding radiant barrier installation costs.

4.4 Conclusions and Recommendations for the Dairy Sector

4.4.1 Summary of Fraser Valley Dairy Context

The most common heat management practices/technologies being used by Fraser Valley dairy producers include natural ventilation (e.g. openings inside walls and end walls) with additional circulation (e.g. fans). A small number of producers are using of radiant barriers on the underside of barn roofs, and high-pressure evaporative cooling systems (e.g. misters). Most barns have automated climate control systems to turn air circulation systems on and off. Producers have noted some impacts of extreme heat already, but most feel that the heat events are not yet frequent enough to warrant substantial investments in additional cooling technologies or management practices.

Opportunities for further technology adoption by the Fraser Valley industry include:

- Use of apps to measure THI: The use of Thermal Aid and/or other free apps to estimate the level of heat stress in herds is not widespread.
- Fan circulation: Some naturally ventilated barns in the Fraser Valley do not have fans or if fans are present, they are not adequate to provide the appropriate cooling effect. Ensuring that existing and new systems are installed properly could maximize cooling effectiveness and be of considerable benefit to dairy producers. High Volume Low Speed fans are being adopted by some dairy operators, but axial fans remain the most common.
- Exhaust ventilation: No installations of tunnel or cross-flow ventilation systems were identified in the Fraser Valley dairy sector. With an increase in extreme temperatures, the use of these systems is likely to increase in the region.
- Evaporative cooling: There is limited use of sprinklers for cooling, and a relatively small number of dairy producers are using misting (fogging) systems in the Fraser Valley. More information for producers on installation and management of evaporative cooling could enhance effectiveness and/or increase uptake of these systems.
- Conductive cooling: No examples of conductive cooling were identified in the Fraser Valley (although water beds are used in some circumstances). This area of research is new and should be followed closely as study results and new information become available.
- Forage crop management: With warmer and drier conditions, some dairy producers in the Fraser Valley are weighing the costs and benefits associated with investing in irrigation for forage crops. Those that currently irrigate tend to be on sandier soils and have access to a good water supply. Improving soil water retention through practices such as conservation tillage and enhanced organic matter may provide a lower cost option for strengthening resilience to hotter and drier conditions. Additionally, changes to cropping systems – different forage species or varieties – have potential to increase yields and/or heat tolerance.

4.4.2 Recommendations for Dairy

Several opportunities exist to gather more information, undertake knowledge transfer and/or evaluate specific technologies for applicability to the dairy sector in the Fraser Valley. These include:

1. Clarify potential transferability, producer interest and current uptake of heat stress apps. If interest exists, conduct pilots/trials of available heat stress apps (e.g. Thermal Aid) to evaluate their applicability for the Fraser Valley dairy sector.

2. Develop fact sheets that provide technical and economic information for:
    - Installation of variable speed drives
    - Upgrading to High Volume Low Speed fans
    - Various evaporative cooling systems (sprinklers, misters)
    - Radiant barrier insulation installation

3. Further explore the feasibility of conductive cooling technologies through applied research or pilot projects that include cost-benefit analysis.

4. Host field days/farm tours that highlight successful installations/applications of heat abatement technologies and practices, including:
    - Evaporative cooling systems
    - Radiant barrier technologies

5. Support improved forage resilience under extreme heat conditions through:
    - Assessing available information on forage irrigation best practices and water licensing in the Fraser Valley, and addressing any informational gaps in the resources
    - Supporting enhanced distribution of information regarding irrigation and water management/licensing best practices
    - Investigating feasibility of, and constraints on, increased irrigation demand for forage production in the Fraser Valley
    - Conducting on-farm research/pilots of innovative soil and crop management practices that improve forage production under extreme heat
    - Conducting/supporting crop trials and research into new forage varieties or crops

5.0 Berry Sector

5.1 Overview of Heat Impacts on the Berry Sector

For the purposes of this report, a focus has been placed on blueberries, as this is the predominant berry crop produced in the Fraser Valley. Whenever possible, impacts and mitigation solutions for other key berry crops, such raspberries and strawberries, are also provided.

High temperatures impact both yields and quality at various points in the blueberry, raspberry, and strawberry production cycles. Consequently, the berry sector may be negatively affected by heat events throughout plant growth cycle, as well as during harvest and processing.

In the spring, high temperatures during bloom can reduce fruit set by shortening the pollination period (by causing a decrease in viability of pollen)[160]. High temperatures during fruit development can decrease berry size and cause sunburn (scald on blueberries, or white drupelets on raspberries (Figure 18)) and/or reduction in firmness of berries, all of which decrease fruit quality and marketable yields. High temperatures in mid-summer may lead to rapid ripening and can cause an overlap in the timing of berry harvest (e.g. raspberries and blueberries are ripe at the same time). This is a particular problem for Fraser Valley growers as a high proportion of blueberries are 'Duke', an early-season cultivar, and hotter summer weather results in greater overlap with the raspberry harvest, placing constraints on labour availability. The compression and overlap in harvest times can result in reduced yield and quality (due to an inability to harvest in a timely manner).

Extreme heat impacts do not end once berries are harvested. Post-harvest, berries must to be cooled quickly to maintain fruit quality. High temperatures during harvest increase the potential for spoilage in bins as the berries are being brought out of the fields. During heat events, berries can be transported more frequently to the packers (for fresh market berries) and processors (for frozen market), but often there is a wait time. This "bottleneck" at the packing and processing facilities occurs because many of the berries in the Fraser Valley ripen and are harvested within a relatively narrow time window. Berries awaiting processing are stored outside in the hot sun, reducing fruit quality, lowering the market grade, and reducing producer profit.

In late summer (e.g. August and September), if high temperatures occur during the day and nighttime temperatures are above average, berry plants take longer to terminate growth and develop fewer fruit buds for the following year.

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[160] Miller, W. 2015. Using Shade Cloth on Blackberries.

FIGURE 18. SUNBURN ON RASPBERRY FRUIT[161]

Berry producers are already managing for several challenging pests such as the spotted wing drosophila (SWD), mites and thrips. It is unclear whether increases in extreme heat events will influence the prevalence and impacts of these pests. In some cases, pest pressure is expected to increase (e.g. more frequent and severe mite outbreaks in hot and dry weather). Producers indicate that SWD impacts generally decrease during extreme heat, as the insect thrives at temperatures of around 20°C. However, cooling management techniques that add humidity to the air (such as misting) can create environments where SWD and other pests, as well as fungal diseases, can thrive.

5.2 Berry Heat Abatement Technologies and Management Practices

The most effective methods for heat abatement of berry crops include preventing direct sun from reaching the fruit (e.g. barrier, shade, or spray) or creating a cool environment for the berry (e.g. reduction in ambient air or use of a refrigerator). The technologies and management practices presented below are used in other berry-producing jurisdictions facing extreme heat conditions and have been identified by Fraser Valley berry stakeholders as having potential applicability within the region. Many of the examples provided pertain specifically to blueberry production. However, technologies and management practices that may be applicable to other berry crops (raspberry, blackberry, strawberry) are specified where possible. Each technology or management practice is described and extent of use within other jurisdictions is outlined, along with considerations for adoption within the Fraser Valley.

5.2.1 Reflective Tarps

Reflective tarps are used post-harvest to prevent berries from heating up as they await transport to packing and processing plants. Reflective tarps are made of laminated fabric with a woven polyester core, which is double coated with bright white on the outer surface and a silvered Mylar® on the under surface[162]. The

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[161] Maughan, T., Drost, D., Black, B., and S. Day. 2017. Using shade for fruit and vegetable production. Utah State University Extension. Horticulture/Fruit/2017-02.

[162] Field to Packer: Postharvest Methods for Fruit Quality. 2019. Agriculture and Agri-Food Canada.

tarps are draped over fruit bins, with the white side facing the sun and the shiny metallic silver surface facing the fruit. The tarps are placed over the bins of berries in the field and remain in use through transport to the packers and processors (Figure 19)[163].

Reflective tarps are used extensively in the BC cherry industry. BC Tree Fruits, which represents about one-third of the cherry production volume in British Columbia, requires that premium and export growers use these tarps. Growers cover bins while cherries are in the field awaiting transport and tarps are also used to cover cherries being transported via flatbed truck to packing facilities[164].

FIGURE 19. REFLECTIVE TARPS BEING USED DURING CHERRY HARVEST.

In 2004, Agriculture and Agri-food Canada conducted a trial in Abbotsford to assess the impact of reflective tarps on blueberry fruit quality[165]. When tarps were used to protect the fruit in the field, only 7.7% of the fruit would have been considered unacceptable when received by a buyer or consumer. In contrast, it was estimated that 23.7% of the fruit left unprotected after harvest and before cooling would have been unacceptable. The superior quality of the tarp-covered blueberries was due to the lower fruit pulp temperatures and higher humidity in the airspace surrounding the fruit. Potential disadvantages include food safety considerations as the tarps must be sterilized between uses[166]. However, this can be managed by using disinfectant sprays or other simple cleaning agents. The costs of the tarps range from \$2 - \$5 per m^2, depending on thickness, perforation, and weighting[167,168].

Current and Future Applicability to Fraser Valley Producers

There has been limited adoption of reflective tarps in the Fraser Valley berry industry, but it has not become standard practice. Concerns remain regarding best practices (e.g. food safety protocols), as well as additional labour requirements in the field.[169].

A variation on the reflective tarp could be to create shade structures for multiple bins of harvested berries that don't touch the berries directly. These shade structures could be used in the field prior to the bins being loaded onto trucks for transport. Use of shade structures outside the packhouses and processing facilities could also reduce the heat exposure of berries. Some facilities have awnings for this purpose; however, the majority of berries are not shaded after harvest and prior to processing.

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[163] Good Fruit Grower, 2008. How reflective cloth affects the crop: The Washington Tree Fruit Research Commission has studied the effects of reflective cloths in apples, pears, cherries, and peaches.

[164] Cool cherry covers. 2018. The good fruit grower.

[165] Toivonen, Peter MA, et al. "The use of reflective tarps at harvest to improve postharvest quality of blueberries." Canadian journal of plant science 84.3 (2004): 873-875.

[166] Interview with Fraser Valley specialist.

[167] AliExpress – Agricultural double sided PET reflective Mylar film: greenhouses, fruit trees, apples, grapes.

[168] Prices for Bushpro Tarps. Can also be found at Deakin Equipment in Vancouver

[169] Berry producer, personal communication.

5.2.2 Shade Cloth

Solar injury of berry plants and fruit can be reduced through use of artificial (cloth screening) shade. This method helps to decrease the amount of radiation that reaches the fruit and mitigates sunburn damage. Shade cloth, or tunnels, can be installed over the top of, or between, berry plants in the field to protect fruiting berries from damaging UV radiation and to provide a cooling effect. Shade cloth is comprised of loosely woven polyester and can provide varying degrees of shade depending on its opacity (e.g. 5-95% shading)[170]. For most fruits, 20-40% shading is ideal. The cloth is permeable to enable rain and/or irrigation water to reach the plants/soil.

Shade cloth tends to reduce air temperature under the cloth, around the berry plants, during the day, and slightly elevate temperatures at night. At night, the shade cloth reflects some of the longwave radiation, resulting in a rise in air temperature. Fruit surface temperature, an important indicator of sunburn potential, is significantly reduced by shade cloth. A study conducted in Utah found that – during the warmest hours of the day - shaded fruit were more than 10°C cooler than unshaded fruit[171]. Shading also increases relative humidity under the structure, which decreases evaporation and causes soil and plants to retain more moisture. Careful water management is therefore required to avoid conditions that may lead to fruit rot or fungal growth.

FIGURE 20. VERTICAL SHADE STRUCTURE[172].

Shade cloth should be installed once fruit has set to ensure that the plants grow to their maximum vegetative capacity. Shade cloth can be installed either horizontally or vertically (Figure 20). Raspberry growers may need to build a higher trellis to accommodate longer canes when growing under shade. Using quality materials for shade cloth support (posts, wires, fasteners) is important for durability, particularly to ensure the structures aren't damaged by wind. Initial cost of installation of support systems can be high, but increased productivity and fruit quality over the life of the structure may offset these costs.

Costs for shade cloth are typically less than $5 per m^2 of material, with costs increasing if percent shading of material required is higher. Knitted shade cloth has a functional life of 7 to 10 years if properly installed.

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[170] Miller, W. 2015. Using Shade Cloth on Blackberries.

[171] Maughan, T., Drost, D., Black, B., and S. Day. 2017. Using shade for fruit and vegetable production. Utah State University Extension. Horticulture/Fruit/2017-02.

[172] Ibid.

Poles (framing), suspension wire, clips for securing the fabric, and pole anchorage all add to the cost of building the structure. Shade cloth can be removed after harvest or when conditions that promote sunburn cease. Storing the cloth under cover during winter months will extend its life. Installing and removing shade cloth adds to annual labour costs, which may or may not be feasible for producers to absorb, depending on the scale of their operation.

The working environment under the shade cloth, cost of materials and labour, and edge effects, must all be considered in the cost-benefit of shade systems. Enough space must be left beneath the cloth for easy movement of labourers and equipment

Jurisdictions where shade cloth is used in berry production include Utah, California and Chile, where the UV radiation causes reduced berry yields. In Chile, hot summers require that fruit production occur earlier in the season, which has forced growers to plant under greater environmental stresses (temperature, radiation, and relative humidity). Research conducted in Chile indicates that different colours of shade cloths block various percentages of UV radiation and can increase fruit yield[173].

Current and Future Applicability to Fraser Valley Producers

Solar radiation in the Fraser Valley is not as intense as in the jurisdictions where shade cloth is currently used. Therefore, the use of shade cloth in the Fraser Valley may decrease the photosynthetically active radiation (the portion of sunlight required for plant growth) reaching the crop, however no research has been done to date[174]. Shade cloth material is affordable, but installation requires additional labour costs and some structures may not be compatible with machine harvesters.

More local research is required to determine if there are specific designs and practices for use of shade cloth (such as the orientation of the installation, the colour of the shade cloths) that would enhance the benefits of this system to the Fraser Valley berry sector. There may also be associated production challenges or co-benefits that require further assessment in a field setting. For some producers – such as those producing without mechanical harvesting – the system may be more feasible.

5.2.3 Cooling Systems

Mobile In-Field Cooling

Portable cooling units can be used to cool berries in the field immediately following harvest (Figure 21). Large-scale units are mounted on flatbed trailers and towed behind a truck while small- scale mobile units can be designed to fit onto the back of pick-up trucks or in small mobile trailers. The units are powered by generators or electricity hook-up and can be moved around in the field as needed.

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[173] Retamales, J. B., Montecino, J. M., Lobos, G. A., & Rojas, L. A. (2006, August). Colored shading nets increase yields and profitability of highbush blueberries. In *XXVII International Horticultural Congress-IHC2006: International Symposium on Cultivation and Utilization of Asian, 770* (pp. 193-197).

[174] Stakeholder comment.

FIGURE 21. PORTABLE COOLER[175].

Large in-field cooling units are used by large berry operations in California and Washington, often when fields are a long distance from the packing and processing facilities. Two examples of large-scale cooling units available are:

- ColdPick Company[176] has developed the ColdPICK M1, a mobile postharvest pre-cooler designed for placement in field next to a picking crew. A standard 20-person labour crew typically picks one stack every 10-15 minutes. The speed and efficiency of the ColdPICK M1 enables stacks to be continuously loaded and moved through the system as they are harvested. Costs are around $270,000 CAD per unit[177]. These units are used in remote blueberry growing areas of Washington.
- The Cold@Field system is used by Naturipe in California for cooling strawberries. The strawberries can be pressure cooled down to 0°C in a self-contained, portable Cold@Field berry cooling system, which is placed at the entrance to the field. The transportation trailer can load from a temperature-controlled dock, eliminating storage time and reduced handling and temperature variations[178]. Equipment dealers estimate costs of these units at around $560,000 CAD.

Small-scale portable coolers can be designed to fit into smaller mobile trailers. Costs can range from $4000 -$5000[179]. Examples of suppliers and designs can be found at the following links:

- Coolbot,
- North Carolina State University,
- University of Florida and
- University of California Davis.

Current and Future Applicability to Fraser Valley Producers

The potential for cooling units to have applicability/uptake in the Fraser Valley was referred to by a number of interviewees, but they were not aware of any current use of mobile cooling units in the sector. Producers growing for the fresh market would likely benefit most from these cooling technologies as the berry quality would be preserved. These systems are likely to be most worthwhile for producers who endure long wait times between harvesting and product delivery. The scale of berry operations in the Fraser Valley may be

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[175] ColdPick M1. Cold Pick Mobile Pre Coolers.
[176] Ibid.
[177] More details can be found in this spec sheet.
[178] Naturipe unveils Cold@Frields in-field cooling system. 2012. Naturipe.
[179] Other Walk-In Cooler Construction Plans. Coolbot.

too small for the large-scale cooling units to be economically feasible. A shared investment in a cooling unit that services several fields could make the price of the unit more reasonable. The smaller portable cooling units may be more feasible for individual producers to purchase or build for their operations. More research is needed to determine what scale of production is needed to make small and large cooling units practical and economical.

Stationary In-Barn Cooling Systems

Stationary cooling units can comprise of walk-in refrigerators or air-conditioning or forced air units housed in a barn or an out-building. Berries are placed into the units directly post-harvest to provide a cool environment until they can be transported to the packhouses and/or processing facilities.

There are many suppliers providing stationary cooling systems for vegetable and fruit production throughout Canada and the United States.

Examples of suppliers of stationary coolers include:

- Jet-Ready™ Pre-cooler forced air cooling tunnel, preassembled, tested, and ready-to-use. It includes energy-efficient fans and electrical controls, mounted on a heavy-duty structural steel frame[180]. The cost is $25,000 – $40,000 CAD per unit, which can hold 8 to 24 pallets, depending on commodity, packaging, and temperature profiles.
- The Coolbot unit can be purchased as a small walk-in cooler and can bring temperature down to to 4.4°C in approximately one hour. Unit sizes start at 2.5 m x 2.5 m x 2.5 m and cost approximately $10,000 CAD[181]. A coolbot controller can be purchased individually which allows producers to construct a system that meets their cooling needs and specific design requirements.

Current and Future Applicability to Fraser Valley Producers

Those interviewed for this project were not aware of any local berry producers using stationary in-barn cooling units. For these systems to be most effective, berries must be moved quickly from the field into coolers. Having cooling systems on-farm may enable producers to reduce quality impacts prior to transport and enable them to plan their deliveries to the processing and packhouses to minimize wait time in the direct sun.

5.2.4 Overhead Sprinklers and Micro-Sprinklers

Overhead sprinklers and micro-sprinklers can be used to provide evaporative cooling for berries. These sprinklers are widely used within the agricultural sector for a variety of crops. Water is sprayed onto the fruit from above the plant and provides evaporative cooling by increasing water vapour around the plant, as well as providing irrigation.

While overhead sprinklers have historically been used to irrigate and cool blueberries during heat events, most new blueberry, raspberry and strawberry fields are irrigated by drip systems[182]. Some Oregon growers

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[180] Jet-Ready Plug N Play Precooler. PreCoolers Post Harvest Systems.
[181] Energy Efficient Walk-In Coolers. Coolbot.
[182] Yang, F. H. 2018. Predictions and practices for reducing heat damage in northern highbush blueberry (Vaccinium corymbosum L.). University of Oregon.

are installing dual irrigation systems and including micro-sprinklers to provide cooling of fruits. A study at Oregon State University investigated the cooling effect of sprinklers and micro sprinklers on blueberry crops and results indicated that both were effective at reducing fruit temperature and improving fruit quality. Using micro-sprinklers with short cycles may optimize fruit growing conditions because less water is used, and excessive wetness is avoided[183].

Current and Future Applicability to Fraser Valley Producers

The majority of Fraser Valley berry producers have transitioned to drip irrigation for water conservation purposes. Producers would therefore be making a considerable investment to install (or re-install) overhead sprinklers or micro-sprinklers. The cost of these systems may be offset by the improvement in berry quality if the fruit is picked for the fresh market. However, overhead sprinkler systems may not be suitable for machine harvested berries due to size and shape of the harvesters (Figure 22).

Use of overhead sprinklers would also increase agricultural water use and this may not be desirable if there are future supply limitations and/or water is critical for meeting irrigation needs. Another consideration is the potential effects of the overhead application of water on pesticide spraying cycles, and on pest populations (e.g. Spotted Wing Drosophila which prefer humid and cool air) and fruit pathology.

FIGURE 22. BLUEBERRY HARVESTER IN DELTA, BC[184].

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[183] Ibid.

[184] Hot For Blueberries. 2017. The Grower.

5.2.5 Protective Coatings and Plant Sprays

Protective Coatings

Protective coatings work by covering the fruit and forming a protective barrier to reflect solar radiation. These particle-based sprays are used in multiple fruit sectors (e.g. cherries, apples)[185]. The coatings can lower the surface temperature of apples by 6°C to 8 °C[186]. Coatings have the potential to increase water use efficiency of plants and may replace evaporative cooling techniques used for reducing sunburn and heat stress in some horticultural crops[187]. However, there are some drawbacks to the use of protective coatings including the added cost and labour associated with removing the coating at harvest time, and the potential for coatings to be washed off by precipitation and/or overhead irrigation, reducing effectiveness and requiring additional applications[188].

Examples of protective coatings used in the cultivation of fruit include:

- Purshade® Solar Protectant: a spray that may reduce solar stress in crops by protecting the plant and fruit from damaging UV radiation and infrared (IR) radiation while still allowing photosynthesis to occur. The reflective properties of Purshade protect fruit from direct sunburn damage and help prevent heat stress in the entire crop canopy[189,190].
- CropBlock: a liquid suspension of technical grade calcium carbonate that is applied to assist in the prevention and reduction of sun burn damage to fresh produce, cherries and grape crops. It is used in fruit production in Australia[191].

Another example of a protective coating is Surround®WP which is a kaolin clay-based particle coating product. This product is available to organic and conventional fruit and vegetable growers in Canada. The product is mainly used for protection against insect pests; however, it is also used as an overall protectant from environmental factors (e.g. sun and rain). Surround®WP has been used by apple growers in Canada to protect against sunburn in 'fair skinned' cultivars and help keep the plant cooler on hot days. The particles in Surround®WP are small enough to allow the wavelengths of light required for photosynthesis to pass through the film, while blocking out or reflecting some of the harmful infrared and ultraviolet radiation[192].

A 2003 study conducted in Mississippi found that the application of Surround®WP on southern highbush blueberries at pre-fruit (50% bloom) provided an increase in number of fruits on each plant. Yield enhancement was obtained without any significant residue on the berries when applied before fruit set. Later single applications, after fruit set, were not beneficial and a kaolin residue, although organic, was evident on berries[193].

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[185] Sharma, R. R., Reddy, S. V. R., & Datta, S. C. (2015). Particle films and their applications in horticultural crops. *Applied Clay Science*, *116*, 54-68.
[186] Ibid.
[187] Ibid.
[188] Sunburn in Fruiting Vegetables and Fruit Crops and Sunburn Protection. 2016. University of Delaware.
[189] PurShade-O Label.
[190] Plant Health, Purshade. Nova Source.
[191] Liquid Crop Block. Ultimate Agri Productions.
[192] Surround WP Crop Protectant Against Insect Pests for Organic and Conventional Fruit, Vegetable and Tree Nut Production. 2013. Agriculture, Aquaculture and Fisheries, Government of New Brunswick.
[193] Spiers, J. D., Matta, F. B., & Marshall, D. A. (2003). Effects of kaolin clay particle film on southern highbush (Vaccinium corymbosum L.) blueberry plants. *Small Fruits Review*, *2*(4), 29-36.

Parka^{TM} is a cuticle supplement made from food grade, elastic, hydrophobic biopolymers that protects the cuticle, which provides a barrier against intrusion by disease, protects against environmental stresses and helps regulate transpiration[194]. Parka^{TM} is applied to foliage and fruit to allow for increased elasticity of the fruit cuticle and to reduce fruit cracking. Parka was developed by Oregon State University and used in sweet cherries to reduce fruit cracking (in some cases it also advanced maturity of cherry fruits). In 2013 and 2015 Parka was tested on the 'Tifblue' and 'Brightwell' rabbiteye blueberry in Georgia and the product reduced fruit splitting during rainfall. However, another study found that Parka had no consistent impact on fruit quality, firmness, shelf life, yield in 'Elliott', or splitting in 'Legacy' blueberries in a trial in Oregon[195].

Plant Sprays

Spray products are available which may support plant health or improve pollination during periods of extreme heat, and hot and dry periods.

Examples of sprays to improve plant health:

- PollinAid can be sprayed on plants to lengthen the viability of the plant pollen. If periods of extreme heat occur during the pollination period, this product could improve pollination (i.e. less aborted fruit and larger fruit size).
- Kelp products applied as a foliar spray or through drip irrigation systems may increase a plant tolerance to drought by helping plants to take up water and effectively retain moisture[196].

Many of the above examples of coatings and sprays indicate that they could be used on berries, however, the consultants assert that the use of these products for berry production would require both scientific evidence of efficacy as well as a lack of negative effects.

Current and Future Applicability to Fraser Valley Producers

It is unclear to what extent producers are currently using protective coatings and sprays in the Fraser Valley berry sector. Parka^{TM} has been used over the past few years by some producers in the Fraser Valley; however, whether increases in use are in response to higher temperatures or for general health benefits to the plant is uncertain[197]. Future research can identify producers using this product to determine effectiveness of coating for mitigating heat impacts on fruits. While there is limited research providing evidence that these coatings and sprays are applicable to the Fraser Valley berry industry, some producers and consultants indicate that this may be an avenue worthy of investigation[198]. More research is needed to assess the feasibility of coatings and sprays for the berry sector.

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[194] Parka, Shield Against Elements. Belchim Crop Protection Canada.

[195] Vance, A. J., & Strik, B. C. (2018). New Foliar-applied Biofilm Had No Impact on Splitting or Fruit Quality in 'Elliott'and 'Legacy'Blueberry in Oregon. *HortTechnology*, *28*(6), 836-842.

[196] Ibid.

[197] Comment from Stakeholder.

[198] Personal communication, blueberry producer.

5.2.6 Harvesting at Night

Harvesting berries at night, when temperatures are cooler, helps to maximize berry quality post-harvest and may be particularly beneficial for the quality of berries grown for the fresh market. Night harvesting is common practice for the wine grape sector in Washington State[199]. Fluorescent or LED lights are mounted on mechanical harvesters or specialized movable towers for fields that are being manually harvested (Figure 26)[200]. Farm workers can harvest under more comfortable conditions than during hot, sunny days and the feasibility of multiple shifts per day is enhanced – speeding up the harvesting process. Separating the berry from the plant may also be easier if done at night when the plant is less stressed from heat.

FIGURE 23. NIGHT HARVESTING OF STRAWBERRIES IN CALIFORNIA[201].

Night harvesting is a relatively common strategy for table grape, apple, sweet corn, and melon growers in various parts of the United States[202]. In the Pacific Northwest USA (e.g. Washington State and Oregon), packhouses and processing plants operate all night to accommodate night harvesting.

Florida and California strawberry growers also harvest at night to increase productivity and fruit quality[203]. LED lighting options are added to conveyor belt strawberry harvesting systems. Harvesting begins around 3 a.m. and the quality of the berries is higher than when picked in daytime temperatures. Some producers have seen an increase in labour supply, due to the improvement in working conditions.

Current and Future Applicability to Fraser Valley Producers

Some producers in the Fraser Valley already harvest at night or early in the morning (before 10am) to reduce negative heat impacts – particularly during peak harvest periods on farms that are serving the fresh market[204]. However, it is unclear if labour availability can support more widespread adoption of this practice, as some labourers may not be willing to work at night. This practice would also be optimal if it

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[199] McFerson, J. R., 2013. Is nighttime the right time for harvest? Growing Produce.
[200] Ibid.
[201] Equipment sheds light on strawberry harvest at night. 2014. The Packer.
[202] McFerson, J. R., 2013. Is nighttime the right time for harvest? Growing Produce.
[203] Equipment sheds light on strawberry harvest at night. 2014. The Packer.
[204] Personal communication, blueberry producer.

could be aligned with Fraser Valley packhouses and processing facilities being open during the night to alleviate long wait times associated with daytime deliveries.

5.2.7 Berry Transportation and Delivery Practices

Berries continue to respire and produce heat post-harvest, therefore the fruit should be delivered to the packinghouse or processing facility as quickly as possible and always within 4 hours of harvest[205]. This may require more than one delivery during a day of harvesting. More frequent delivery trips will increase fuel and labour costs; however, the improved quality of the berries may provide positive economic returns.

Supply chain logistics adjustments have also been shown to improve product shelf life. A study based in Mexico indicated that 57% of the blackberries arriving at the packinghouse did not have enough remaining shelf life for the required supply routes. Techniques adopted by the packinghouses can also impact berry quality. Simple temperature measurements can be conducted that result in a 'first expiring first out' technique for packinghouses[206].

Current and Future Applicability to Fraser Valley Producers

Fraser Valley stakeholders indicated that alleviating the bottleneck that exists with regard to berry deliveries at packinghouses and processing facilities would improve the quality of the fruit being processed. Currently, there are periods of time when harvest volumes are so high in the Fraser Valley that processing and packaging facilities struggle to accept fruit in an efficient timeframe, resulting in line-ups of trucks waiting to deliver fruit during the hottest time of the day. This is compounded by the fact that most blueberry producers are growing the same variety (e.g. Duke), which are all ready for harvest at the same time, and often overlap with the raspberry harvest[207].

Potential solutions to this issue include longer hours for processing and packaging facilities (opening earlier and/or closing later) during periods of intensive harvesting. Use of shading structures at the packing/processing facilities or use of reflective tarps on the individual trucks would also assist in keeping berries cool. If high temperatures occur and there is not a delay at the processing/packaging facilities, producers could also increase the frequency of deliveries.

5.2.8 Plant Genetics and Breeding Initiatives

Heat impacts on blueberry crops can potentially be alleviated by breeding cultivars that are more drought and heat tolerant, and by experimenting with varieties that respond differently to day length. Research suggests the greatest challenge associated with expanding the geographic range of blueberries in a changing climate is the development of cultivars that can withstand extremes in environmental variability.

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[205] Boyette, M., Estes, E., Mainland, C.M., and Cline, B. 1993. North Carolina State Extension. Postharvest cooling and handling of blueberries.

[206] Nunes, C., Nicometo, M., Emond, J-P, and R. Badia-Melis. 2014. Improvement in fresh fruit and vegetable logistics quality: Berry logistics field studies. Philosophical Transactions of the Royal Society A Mathematical Physical and Engineering Sciences. 372(2017).

[207] Feedback from stakeholders - In some cases, even for processed fruit, packers have been calling growers and asking them not to harvest for a few days or only allowing each grower to ship half of what they would normally ship due to large volumes of fruit being harvested in the valley at a given time.

However, researchers believe that breeding programs can further enhance cold acclimation as well as tolerance of heat, high UV, and drought[208].

For example, one of the BC Berry Breeding Program's objectives is to breed blueberries for higher latitudinal adaptation so that future varieties set more flower buds under local day-length conditions. Observational trials conducted at the University of California indicate that new southern highbush blueberry cultivars, which require fewer "chill hours" to produce fruit, are well adapted to the San Joaquin Valley climate[209].

A study completed in 2015 at Washington State University evaluated new cultivars developed by public and private breeding programs within the climactic conditions of northwest Washington[210]. Cultivars included in the study were: 'Top Shelf', 'Blue Ribbon', 'Calypso', 'Clockwork', 'Last Call', 'Cargo', and 'Baby Blues'. In this trial study, 'Top Shelf' had the greatest yield in 2016, followed by 'Blue Ribbon', 'Calypso', 'Duke', 'Clockwork', 'Last Call', and 'Elliott'. Yields were lowest for 'Bluecrop' and 'Liberty'. More research is continuing at Washington State University to provide further information regarding the adaptability of these cultivars in the northwest Washington blueberry industry. In Oregon, researchers are conducting studies of varying irrigation methods (drip, overhead, micro spray, and timings for blueberry cultivars to aid in maintaining yield and fruit quality with less water, as reduced water available is expected in the future[211,212].

Current and Future Applicability to Fraser Valley Producers

Changing berry varieties would be a long-term and costly transition for Fraser Valley blueberry growers (and would involve considerable time-lag for return to productivity for growers). However, this approach may play a role as a longer-term solution to address various production issues. As cultivars better suited to the changing conditions in the region are released for commercial production, berry producers may decide to undertake small-scale trials or to replant with newer varieties that are locally developed. Support for more local trials could enhance knowledge of varieties and local performance.

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[208] Lobos, G. A., & Hancock, J. F. (2015). Breeding blueberries for a changing global environment: a review. *Frontiers in plant science*, *6*, 782.

[209] Blueberry research launches exciting new California specialty crop. 2005. University California, Kearney Research and Extension Center - California Specialty Crop.

[210] DeGraw, C., Watkinson, S., DeVetter, L.W. 2016. Highbush Blueberry Cultivar Trial in Northwestern Washington. Vol. 5 Iss. 9. Washington State University.

[211] Almutairi, K. F., Bryla, D. R., & Strik, B. C. (2017). Potential of Deficit Irrigation, Irrigation Cutoffs, and Crop Thinning to Maintain Yield and Fruit Quality with Less Water in Northern Highbush Blueberry. *HortScience*, *52*(4), 625-633.

[212] Irrigation Guidelines for better blueberry production. David Bryla, USDA.

5.3 Summary Table of Technologies and Management Practices for the Berry Sector

Technology	Where It Is Used	Costs	Weaknesses	Strengths
Reflective Tarps	BC cherry industry	Costs range from \$2-\$5/m^2 for a reusable tarp[213]:	Potential for food safety issues, must be disinfected.	Reduces spoilage post-harvest (Abbotsford-based study documented a decrease in spoiled fruit from 24% to 8% with tarp use).
Shade Cloth	California Utah Chile	Shade cloth material is inexpensive (about \$5/m^2) but infrastructure, installation and maintenance costs may be high.	May reduce photosynthetically active radiation. May not be feasible with machine harvesting. Increased labour needs to install and remove from fields.	Reduces sunburn on plants which maximizes berry quality. Several orientation options to accommodate field equipment. Potential for packing and processing plants to provide shade structures.
Mobile, in-field cooling	California Washington	Large-scale: \$270,000 for a self-contained cooling system that can hold 1,500-1,800 lbs of berries[214]. Small-scale: Costs start at ~\$5,000[215]	Costs of large-scale units may be too high for individual producers to absorb. Practicality of small-scale units depends on production scale. Power source required; increased energy costs.	Maximizes berry quality right at the point of harvest. Producers may be able to pool resources and share a cooling unit in a central location. Allows for the producer to have more control over the heat impacts on berries from the point of harvest up until processing, with no gaps. Reduce cull rates by preventing premature spoilage.

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[213] Prices for Bushpro Tarps. Can also be found at Deakin Equipment in Vancouver.

[214] Discussion with ColdPick dealer.

[215] CoolBot trailers dealership website.

Technology	Where It Is Used	Costs	Weaknesses	Strengths
Stationary in-barn cooling systems	Washington Oregon	Costs range from \$25,000 – \$40,000 per unit, depending on size[216]	Space is required to house cooling unit in barn or outbuilding. Adds additional transportation step between harvesting and delivery to processing/packaging facilities. Power source required; increased energy costs.	Provides quicker onsite cooling. Maximizes berry quality and preserves freshness.
Overhead sprinklers and micro-sprinklers	Oregon	Costs highly variable. Depends on types of sprinklers chosen, number of acres and water and labour costs.	Growers have replaced overhead with drip irrigation to reduce water use therefore existing irrigation infrastructure would need to be replaced or supplemented – this would be costly. May not be suitable for machine harvested berries due to size and shape of the harvesters. Could promote SWD and rot if humidity is high and temperatures are low.	Reduce temperature of fruits which improves fruit quality. Provides irrigation as a side benefit.
Protective Sprays	Australia (cherries) Oregon (blueberries) BC - Fraser Valley	Costs highly variable. Depends of product chosen, acres sprayed, and number of applications needed.	Need to consider timing of spraying close to point of harvesting and/or pesticide application. Lack of research on effectiveness of products on berries.	Research found on other crops (e.g. cherries, apples) indicate that the sprays were effective at reducing sunburn on fruits.

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[216] Jet-Ready Plug N Play Precooler. PreCoolers Post Harvest Systems.

Technology	Where It Is Used	Costs	Weaknesses	Strengths
Night harvesting by machine or by hand	Washington Oregon California Florida	Increased labour costs, if assuming harvesting is occurring during the day and night. LED lighting systems may need to be purchased.	For fresh market berries: need to ensure timing does not overlap too much with early morning dewpoint, as berries cannot be picked when wet (dew does not impact frozen market berries). May not coincide with hours of the packhouses and processing facilities to receive the products.	Maintains berry quality compared to harvesting during the heat of the day. Better for worker health and safety (prevents heat stroke).
Increase delivery frequency to packing/processing plants	Mexico	Costs uncertain. Depends on number of deliveries needed.	Costs of employee time and transportation costs. Trucks are not at full capacity, therefore average cost per unit increases. Processing and packing plants may be not be able to process berries immediately due to limited capacities.	Reducing time that berries are exposed to sun will reduce spoilage and increase shelf life and quality.
Plant Breeding and Genetics	Washington Oregon British Columbia	Costs uncertain.	Changing plant varieties would be very high cost and long-term. Lack of pilot testing and trials in the region to provide proof of concept. Longer term solution to high heat impacts.	Varieties able to perform better under high heat, high latitudes, and/or under drought conditions offer promise for increased yields and berry quality.

5.4 Conclusions and Recommendations for the Berry Sector

5.4.1 Summary of Fraser Valley Berry Context

The findings of the stakeholder engagement with berry producers, specialists and researchers confirmed that periods of extreme heat are already having negative impacts on berry yields and quality in the Fraser Valley. However, it was noted that there has not been a shift towards high-tech or investment-heavy methods to mitigate these heat impacts. For many growers, the losses and costs associated with extreme heat have not yet been sufficient to justify investment in new production practices or technologies.

Labour shortages, industry characteristics (e.g. part-time growers, picking for fresh vs. frozen markets), and lack of local demonstration or pilot activity were cited as limiting factors for adoption of new technologies. Nonetheless, extreme heat events will continue to negatively impact yields and quality, and therefore the overall profit of the berry sector in the Fraser Valley. Future increases in summer temperatures, and warmer falls and springs, are likely to increase the willingness to consider additional investments in heat mitigation strategies.

Specific tools and practices that show promise for the Fraser Valley berry sector include:

- Reflective tarps that are used successfully in other BC fruit sectors. More research into the food safety concerns and a cost-benefit analysis of the feasibility of using reflective tarps for each of the berry crops would be beneficial to determine applicability in the Fraser Valley.
- Portable and in-barn cooling systems are effective at quickly cooling berries post-harvest; however, the cost of these systems is high. It may not be economically feasible for one producer to invest in a cooling system, but a cost-sharing scheme may be possible for producers with different harvest schedules.
- There are numerous plant coatings and sprays that could be used to protect berries from damaging UV radiation and to improve overall plant health. More research is needed to the assess qualities of each spray and their applicability to each of the Fraser Valley berry sectors.
- Harvest management practices such as shading harvested fruit or night harvesting could alleviate heat impacts resulting from supply chain bottlenecks.

5.4.2 Recommendations for Berries

Several opportunities exist to gather more information, undertake knowledge transfer and/or evaluate specific technologies for applicability to the berry sector in the Fraser Valley. These include:

1. Develop fact sheets that provide technical and economic information for:
    - Use of reflective tarps for various types of berries including specific information for best practices for food safety;
    - Feasibility of in-field/mobile cooling systems

2. Trial the use of sprays and/or coatings for managing heat/sun damage and assess impacts on berry quality. Partner with researchers and/or industry specialists to oversee research and share results via presentation/field days/fact sheets etc.

3. Trial/demonstrate, and provide economic information for, alternative approaches to harvest management, including:
    - Feasibility of night-time (or extended hours) harvest and delivery to packhouses
    - Potential for producer coordination of packhouse delivery timing, with consideration for increased frequency of delivery during extreme heat

4. Undertake a study to evaluate the efficacy and production impacts associated with the use of over-head sprinkler systems for reducing temperatures. Partner with researchers and/or industry specialists to evaluate the potential impacts on pest and disease pressures and water consumption

5. Facilitate dialogue between producers, industry groups, and researchers to develop blueberry cultivar trials for improved heat tolerance and productivity at the latitude of the Fraser Valley.

5.5 Key Resources

5.5.1 Poultry Sector

Title of Resource (with hyperlink)	Author and Date	Keywords	Summary
Heat Stress in Poultry, Solving the Problem	Government of United Kingdom 2005	Managing heat stress Barn Designs Air Flow	This booklet is intended to describe the main causes of heat stress in poultry. It outlines some of the common sense management measures that will help to prevent it, including barn designs, evaporative cooling, feed and water management and stocking densities.
Heat stress and feeding strategies in meat-type chickens	World's Poultry Science Journal 2011	Managing heat stress Feeding strategies	Article that discusses feeding strategies to reduce heat stress. Strategies such as restricted feeding, variations in protein, energy nutrients and water content in hotter areas than the Fraser Valley. The feeding strategies discussed may help to reduce heat production peaks, facilitate evaporative activity and/or decreases the heat load, resulting in beneficial effects on performance and health of the bird kept in more tropical areas worldwide.
Beat the Heat: Managing Poultry Stress	Poultry Industry Council, Ontario (Video)	Managing heat stress Heat Impacts	This hour video begins with explaining the physiological responses of poultry to various levels of temperatures and relative humidity levels. Impacts on bird immune system, digestive system, egg health, etc. are discussed in detail. Strategies for managing heat stress are discussed including water, feed, additives, barn environment, bird management.
Nutritional management to alleviate heat stress in broilers.	International Journal of Science, Environment 2015	Managing heat stress Feeding strategies	This paper discusses the physiological response of poultry to high temperatures and feeding strategies during heat events. Feeding strategies discussed include fasting, increasing energy context of diet with fat, amino acid balance, protein levels, mineral and vitamin supplements and electrolyte balance.

Title of Resource (with hyperlink)	Author and Date	Keywords	Summary
Code of Practice for the Care and Handling of Hatching Eggs, Breeders, Chicken, and Turkeys	National Farm Animal Care Council, Canada 2016	Managing heat stress Feeding and water strategies Barn Environments	This Code is a guideline for the care and handling of broiler and turkey hatching eggs, broiler and turkey breeders, broiler chickens, and turkeys. Requirements in this Code are intended to be outcome- or animal-based, as they are most directly linked to animal welfare, and can be applied in a wide range of animal production systems. Information discussed in the document include hatcheries, housing and environment, feed and water, flock health management, husbandry practices and transportation.
Ventilation Principles	University of Kentucky	Ventilation Air flow Barn Design Evaporative Cooling	This website provides information on management of ventilation systems during hot weather. The resource discusses: air exchange rates, evaporative cooling, fogging and misting systems, mechanical, tunnel and natural ventilation.
Agriculture Building Ventilation Systems	BC Ministry of Agriculture 2016	Ventilation Barn design Air flow Evaporative cooling	The report identifies what can be done and what is currently being done with respect to livestock building environmental control for the BC dairy, poultry, and swine industries. The report provides an in-depth explanation of all possible ventilation systems for the BC Poultry industry. An analysis of benefits and drawbacks for each system are discussed.
Poultry House Moisture Control Spreadsheet Tunnel Ventilation Management Tips Evaporative Cooling Pad System Water Usage. Using Interval Timers to Control Evaporative Cooling Pads.	Michael Czarick University of Georgia	Ventilation Barn design Air flow Evaporative cooling Tunnel Ventilation management	These resources come from the University of Georgia's 'poultryventilation.com' website. There are a multitude of concise documents on topics including: on how to manage poultry barn ventilation in hot weather, tunnel ventilation, exhaust fans, air circulation, evaporative cooling, automation of systems, water and feeding strategies, stocking densities and maintenance of ventilation systems. There are free excel spreadsheets producers can use on the topics of: moisture control, tunnel air speed, tunnel fan comparison, heat gain in barns, evaporative cooling design and others.

Title of Resource (with hyperlink)	Author and Date	Keywords	Summary
Tunnel Ventilation in Livestock Barns – With and Without Evaporative Cooling.	Ontario Ministry of Agriculture, Food and Rural Affairs 2013	Ventilation Tunnel Evaporative cooling	This Factsheet discusses the design factors and management of tunnel ventilation – with and without evaporative cooling. The resource provides examples of fan sizing and air intake calculations.
Environmental Management in the Broiler House.	Ross Environmental Management 2010	Ventilation Tunnel Evaporative Cooling	This resource goes into depth about ventilation, evaporative cooling and relative humidity concerns and managing tunnel ventilation. The There is a focus on the economic considerations and benefits of effective environmental control of the barn environment.
Tunnel Ventilation of Broiler Houses.	University of Florida Extension 2018	Ventilation Tunnel Evaporative Cooling	A brief, easily readable document outlining: the functions of a ventilation system, how tunnel ventilation functions, evaporative cooling and how it functions and maintaining these systems.
Getting ventilation right on broiler farms.	Poultry World 2018	Ventilation Air flow calculations Maintenance	A short article describing the importance of achieving appropriate ventilation requirements for broiler farms. Maintenance of systems during summer months is discussed.
Fully-packaged ground source heat pumps – designed specifically for the poultry industry.	GEOCUBE	Heat-pump Heating and cooling	This resource is a short explanation of how ground-source heat pumps, designed specifically for the poultry industry, function. Descriptions of energy efficiencies, and variations of the systems are outlined.
Ground source heat pumps harnessed for new broiler unit.	Farmers Weekly 2019	Heat-pump United Kingdom	This article describes a ground source heat pump installed on a UK boiler farm (four barns totalling 200,000 birds).

5.5.2 Dairy Sector

Title of Resource (with hyperlink)	Author and Date	Keywords	Summary
Heat Stress in Dairy Cows, Stress Threshold	Ontario Ministry of Agriculture, Food and Rural Affairs 2011	Managing heat stress Temperature-humidity-index	A concise explanation of the temperature-humidity-index (THI) and levels that animals begin to experience stress. Short descriptions of ventilation systems and cooling systems to reduce heat stress in cows.
Calculating the Temperature-Humidity Index (THI)	Progressive Dairy 2014	Temperature-humidity-index calculation	An explanation of THI, the formula used to calculate THI and examples of how producers can calculate the THI for their barn environments.
Dairy Cooling: The Benefits and Strategies.	University of Wisconsin-Madison 2015	Managing heat stress Economic benefits of cooling Ventilation Evaporative Cooling	This document contains a description of THI and the effects of various THI levels on milk production, dry matter intake and reproduction of animals. Heat abatement strategies such as different types of ventilation, air velocity, and evaporative cooling are detailed.
Evaporative tunnel cooling of dairy cows in the Southeast.	Journal of Dairy Science 2006	Ventilation Tunnel Lactation performance	This study undertook an experiment to compare an evaporative cooling/tunnel ventilation system to a naturally ventilated system in Holstein cows. Under the conditions of this study found that evaporative tunnel cooling reliably reduced exposure to conditions of heat stress and improved milk production of lactating dairy cows during the summer season.
Dairy freestall barn design – a Northeast perspective.	Cornell University 2008	Ventilation Tunnel vs Mechanical	This study describes ventilation systems with and without cooling fans and compared tunnel ventilation with naturally ventilated systems. Examples of air exchange rates for various barn configurations are listed and includes diagrams of ventilation systems.
Effects of heat stress on dairy cattle welfare.	Journal of dairy science 2017	Signs of heat stress Impacts of heat stress	This study describes the physiological responses of dairy cows when their internal body temperature rises due to warm temperatures and high relative humidity. Impacts from high body temperatures are described including a decrease in milk production a decrease in reproductive success.

Title of Resource (with hyperlink)	Author and Date	Keywords	Summary
Agriculture Tips for Improving Forage Establishment Success.	Government of Manitoba	Forage types	Discussion of how to improve forage success. Tips include: preparing the field, weed control, selecting the forage species, seeding, fertility and companion crops.
Selecting a Sprinkler Irrigation System.	University of North Dakota 2018	Irrigation	This document is from North Dakota and describes how to select an irrigation system for different soil and crop types, various types of irrigation systems and the sprinkler system capacity. Types of sprinkler systems included in the document are: wheel roll, traveling big gun, linear move, centre pivot.
Irrigation Management Guide.	BC Ministry of Agriculture 2005	Irrigation	The primary purpose of this B.C. Irrigation Management Guide is to provide irrigation professionals and consultants with a methodology to assess the irrigation system performance and manage the system effectively.
Drought management factsheet: Alternate forage crops when irrigation water is limited.	BC Ministry of Agriculture 2015	Forage crops Irrigation	This factsheet discusses choosing annuals versus perennial crops and characteristics of annual forage crops, including: cereals (in order of drought tolerance): fall rye, spring rye, winter triticale, spring triticale, hard red spring wheat, barley, oats and other annual crops such as pearl millet, sunflower, sorghum, sudangrass, corn.
Strategies to Improve Forage Yield and Quality While Adapting to Climate Change: Optimizing water applications to maximize forage yield during dry summers while at the same time minimizing nutrient losses	BC Agriculture & Food Climate Action Initiative 2018	Forage crops Irrigation	This study evaluated grass response to the two limiting factors, irrigation and nitrogen. In two of three years, there was a very significant response to irrigation increasing yield; in 2015 and 2017 N increased yield by about 1 t/ha with no irrigation but irrigation plus the same amount of N increased yield by 3-5 t/ha. In 2016, the grass responded more to N than to water due to moist conditions, water holding capacity of soils and deep roots in orchardgrass. It is important to avoid leaching nitrate below the root zone with irrigation water. The data in this study should be subjected to economic analysis to determine the overall cost and benefit of watering relative to purchasing additional feed.

Title of Resource (with hyperlink)	Author and Date	Keywords	Summary
Agriculture Building Ventilation Systems	BC Ministry of Agriculture 2016	Ventilation Barn design Air flow Evaporative cooling	The report identifies what can be done and what is currently being done with respect to livestock building environmental control for the BC dairy, poultry, and swine industries. The report provides an in-depth explanation of all possible ventilation systems for the BC Poultry industry. An analysis of benefits and drawbacks for each system are discussed.
Ventilation and cooling in adult cattle facilities	University of Wisconsin-Madison	Managing heat stress Ventilation Evaporative cooling	This document contains check lists to determine heat stress level and natural ventilation vs mechanical ventilation requirements. The document contains specific information regarding fan and cooling requirements for tunnel and cross ventilation systems. Diagrams of efficient ventilation and cooling systems are included.
Dairy Housing - Ventilation Options for Free Stall Barns.	Ontario Ministry of Agriculture, Food and Rural Affairs 2018	Ventilation Evaporative cooling	This Factsheet describes optimal barn environments for dairy cows in free-stall barns. Included are descriptions of ventilation and control systems of barn designs, fan types and considerations and sprinkler systems.
Agricultural Ventilation Systems.	Sun North Systems Ltd	Ventilation Automation	This document contains descriptions of common natural ventilation features of dairy barns including: curtains, panels, chimneys exhaust systems HVLS fans and automation. Useful diagrams and details photos are provided.
Cross-Ventilated Barns for Dairy Cows: New Building Design with Cow Comfort in Mind.	Extension 2013	Ventilation	This resource provides a detailed example of a low-profile cross-ventilated (LPCV) barn design for a dairy barn. Advantages and disadvantages of this design are discussed along with detailed diagrams and photos.
Ventilation of the Milking Complex.	BC Ministry of Agriculture 2015	Ventilation Milking parlor	This factsheet provides diagrams of an example for ventilating the milking parlour and holder area in a dairy barn. Specific details are provided for a recommended negative pressure ventilation system to provide air circulation and reduce condensation.

Title of Resource (with hyperlink)	Author and Date	Keywords	Summary
Conductive cooling: Could it be the new cow comfort concept	Progressive Dairyman 2014	Conductive cooling	This article describes a conductive cooling system with heat exchanger panels buried underneath the sand in deep-bedded freestalls. Cooled water circulates through the closed-loop system, providing heat stress relief to cows as they are lying in the stalls. This concept has the potential to save on both water and energy usage on dairies. While fans are still a necessary component of the heat abatement system, this allows for more targeted energy use.
Water bedding solutions: an innovative tool to combat heat stress.	International Dairy Topics	Conductive cooling Water bedding	This brief document describes a water bedding system designed in France and its effectiveness at cooling cows while they lie down. The water bedding system was shown to dissipate heat under the down, providing increased cow comfort.
Conductive Cooling System for Dairy Farms.	Southern California Edison 2014	Conductive cooling	This document evaluates the effectiveness of conductive cooling technology to reduce energy consumption while alleviating heat stress in lactating dairy cows. The evaluation takes place on a dairy farm located in California's San Joaquin Valley.
Keeping Cows Cool with less water and energy.	University California Davis 2017	Conductive cooling	This article describes conductive cooling technologies being developed at UC Davis to reduce heat stress on dairy cows. Technologies in the article include conduction cooling with a mat and targeted convection cooling (diagrams included).
Modeling conductive cooling for thermally stressed dairy cows.	Journal of Thermal Biology 2016	Conductive cooling	This article presents the results of a modeling study that simulated cooling heat stressed dairy cows using a water mattress. The cooling performance of the water mattress was dependent on the temperature of the recirculating water inside the water mattress.
Genetic research speeds pace of dairy breeding.	The Western Producer 2018	Breeding	The article describes research being conducted at La Trobe University in Australia. Research has indicated that heat tolerance has been favourably linked with fertility and unfavourably with production; which means that a strong focus on heat tolerance in bulls may improve fertility but compromise production. A greater focus on genetic research on female cattle has been proven to be effective at influencing milk production rates under heat stress.

Title of Resource (with hyperlink)	Author and Date	Keywords	Summary
Dairy Update, Quarterly Newsletter.	University of Florida 2018	Breeding	This newsletter briefly describes the research occurring at the University of Florida to breed the SLICK gene into US Holsteins. The SLICK Holsteins are better able to regulate their body temperature during heat stress and experience a less- severe decline in milk yield during the summer than Holsteins with typical hair.

5.5.3 Berry Sector

Title of Resource (with hyperlink)	Author and Date	Keywords	Summary
The use of reflective tarps at harvest to improve postharvest quality of blueberries.	Canadian Journal of Plant Science 2004	Reflective tarps	Effects of covering blueberries with reflective tarps to protect the fruit from exposure to the sun after picking were assessed. Covering fruit with reflective tarps resulted in significant improvement in quality. Improved quality of the blueberries was attributed to the lower fruit pulp temperatures and higher humidity in the airspace surrounding the tarp-covered fruit.
Cool cherry covers.	BC Cherry Industry 2018	Reflective tarps	This article describes how cherry producers used reflective tarps effectively to cool the cherries immediately post-harvest. Tarps are placed over bins and transported to the packhouses with the tarps.
Using Shade Cloth on Blackberries.	Miller Walker 2015	Shade cloth	This PowerPoint describes a study that used shade cloth over blackberries during later summer/fall harvest in South Carolina. The resource describes the system set-up/installation and exmplaiang variation is shade cloth types.
Using shade for fruit and vegetable production.	Utah State University Extension 2017	Shade cloth	This study describes how shade cloth protects plants and berry fruits, the surface temperature of fruit at which sunburn damage occurs, how to manage impact from sunburn and shade cloth options and costs.
Colored shading nets increase yields and profitability of highbush blueberries.	University of Talca, Chile 2006	Shade cloth	This research studies the effects of shading nets (color, shading degrees) on environmental conditions faced by plants, as well as vegetative growth, yield and quality of fruit produced, as well as economic performance in highbush blueberries.
Effects of kaolin clay particle film on southern highbush (Vaccinium corymbosum L.) blueberry plants.	Small Fruits Review 2004	Protective coating	Three separate studies were conducted to report the effects of kaolin applications (Surround WP) on southern highbush blueberries (Vaccinium corymbosum L.) and rabbiteye (V. ashei Reade) blueberries. When applied to mature blueberry plants, kaolin clay emulsion dried to form a white reflective film and affected bud development, fruit set and development, plant growth, and fruit yield, but had no effect on fruit quality parameters.

Title of Resource (with hyperlink)	Author and Date	Keywords	Summary
Sunburn in Fruiting Vegetables and Fruit Crops and Sunburn Protection.	University of Delaware 2016	Sunburn Protective coating	This brief article describes the effects that sunburn has on fruits and advantages and disadvantages of protective coatings to reduce sunburn impacts.
Particle films and their applications in horticultural crops.	Applied Clay Science 2015	Protective coating	This article is a review of academic studies on protective coatings and their use in horticultural crops. The review is particularly focused on history, modes of action, application and a variety of effects of protective coatings on horticultural crops.
Surround WP Crop Protectant Against Insect Pests for Organic and Conventional Fruit, Vegetable and Tree Nut Production	Agriculture, Aquaculture and Fisheries, Government of New Brunswick 2013	Protective coating	This document describes the protective coating "Surround WP" and its applicability to apple, grape, raspberry and strawberry and vegetables growers in Canada. The document gives some guidance on what pests Surround WP may be useful against and recommended applications to fruits.
New Foliar-applied Biofilm Had No Impact on Splitting or Fruit Quality in 'Elliott 'and 'Legacy 'Blueberry in Oregon.	Horticulture Technology 2018	Protective coating	Two trials were undertaken to test the effects of a new protective coating using various application timings and methods. There were no visual defects caused by application of biofilm. Compared with the controls in either study, biofilm had no consistent impact on fruit quality, firmness, shelf life, yield in 'Elliott', or splitting in 'Legacy'.
How to build a mobile walk-in cooler with a CoolBot	CoolBot	Portable cooling system	This article describes the different components of building a portable cooler for fruits and vegetables. The article discusses insulation, air conditioning, power, and provides construction plans.
Cool and Ship: A low-cost portable forced-air cooling unit.	North Carolina State University 1995	Portable cooling system	This resource provides in-depth plans, photos and blueprints for designing a portable refrigerated cooling unit for berry fruits.
A Portable Demonstration Forced-Air Cooler.	University of Florida 2002	Portable cooling system	This resource outlines a demonstration of a force-air cooling unit for vegetable crops. Details from operational testing are described along with how to build the unit.

Title of Resource (with hyperlink)	Author and Date	Keywords	Summary
Pre-cooling systems for small-scale producers. University of California Davis.	University of California Davis 2010	Cooling systems	The purpose of this article was to identify pre-cooling systems and cooling methods that are suitable for smaller scale horticultural producers. The article describes a range of pre-cooling systems that are available for small-scale horticultural producers and their suitability, in terms of availability, ease of use, capital cost, energy requirements. Expected benefits of using pre-cooling are also discussed.
Jet-Ready Plug N Play Precooler.	Post Harvest Systems	Stationary cooling system	This website provides a detailed description of the Jet-Ready Precooler. The Jet-Ready Precooler is a forced air cooling tunnel, preassembled, fully-wired, tested, and ready-to-use. It includes powerful, energy-efficient special-design fans, foam pads and tarp, and all electrical controls, mounted on a Carboline-coated heavy-duty structural steel frame.
Energy Efficient Walk-In Coolers.	CoolBot	Stationary cooling system	This website provides a detailed description of the CoolBot walk-in, stationary cooler. Specifications around refrigeration, construction, operating costs and remote system monitoring are discussed.
Is nighttime the right time for harvest?	Growing Produce 2013	Night harvesting	This article describes night harvesting in the wine grape industry in the US Pacific Northwest. The article discusses the advantages and disadvantages to night-time harvesting.
Equipment sheds light on strawberry harvest at night.	The Packer 2014	Night harvesting	This article describes the practices and machinery used for night-time harvesting in the strawberry sectors of California and Florida.
Postharvest cooling and handling of blueberries.	North Carolina State Extension 1993	Post-harvest cooling Post-harvest handling	This resource describes post harvesting handling techniques and practices to maintain blueberry quality. The article discusses manual and mechanical harvesting, sorting, packing and cooling.

Title of Resource (with hyperlink)	Author and Date	Keywords	Summary
Improvement in fresh fruit and vegetable logistics quality: Berry logistics field studies.	PubMed 2014	Supply chain logistics	This study showed that temperatures inside blackberry pallets varied significantly and 57% of the berries arriving at the packinghouse did not have enough remaining shelf life for the longest supply routes. The study found that by using simple temperature measurements much waste can be avoided using 'first expiring first out'. Results showed that shelf-life prediction should not be based on a single quality factor as, depending on the temperature history, the quality attribute that limits shelf life may vary.
Blueberry research launches exciting new California specialty crop.	University California 2005	Breeding trials	This article describes observational trials at the UC Kearney Research and Extension Center that indicated new southern highbush blueberry cultivars, which require fewer “chill hours” to produce fruit, are well adapted to the San Joaquin Valley climate. In a replicated cultivar evaluation, researchers quantified yields and identified several productive and flavorful varieties.
Breeding blueberries for a changing global environment: a review.	Frontiers in Plant Science 2015	Breeding Climate Change	This paper reviews the environmental challenges facing blueberry cultivation due to global warming. The researchers describe the state of the art of blueberry breeding and outline how future varietal development can be enhanced by marker assisted breeding (MAB) and phenomics.
Highbush Blueberry Cultivar Trial in Northwestern Washington.	Washington State University. 2016	Breeding trials	This report presents preliminary information of new cultivars that may be suitable for commercial blueberry production in northwest Washington. Cultivars included in the study were: ‘Top Shelf’, ‘Blue Ribbon’, ‘Calypso’, ‘Clockwork’, ‘Last Call’, ‘Cargo’, and ‘Baby Blues’. In this trial study, ‘Top Shelf’ had the greatest yield in 2016, followed by ‘Blue Ribbon’, ‘Calypso’, ‘Duke’, ‘Clockwork’, ‘Last Call’, and ‘Elliott’. Yields were lowest for ‘Bluecrop’ and ‘Liberty’.

Title of Resource (with hyperlink)	Author and Date	Keywords	Summary
Predictions and practices for reducing heat damage in northern highbush blueberry (Vaccinium corymbosum L.).	University of Oregon 2018	Overhead sprinklers and micro-sprinklers	In this research cooling sprinklers and micro sprinklers were analyzed for their ability to reduce heat damage and to improve fruit quality of blueberries. Effects of different cooling frequencies on reducing fruit temperature were also evaluated. Results showed that both sprinklers and micro-sprinklers were effective tools for reducing fruit temperature and improving fruit quality. Using micro-sprinklers with short cycles may be the best practice because these use significantly less water than sprinklers and keep fruit from getting too wet.
Irrigation Guidelines for better blueberry production.	David Bryla, USDA.	Irrigation	This report provides details on irrigation practices for blueberry growers and indications of water stress symptoms in plants. Advantages and disadvantages of overhead sprinklers, micro-sprinklers and drip irrigation are discussed.