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**A REVIEW ON FROST PROTECTION SYSTEM FOR AGRICULTURAL APPLICATION**

AMITH PREMAN NARIYANPALLI<sup>1</sup>, ASHUTOSH SINGH<sup>2</sup>, SYEDA TASNIM<sup>3</sup>

<sup>1</sup> Amith Preman Nariyanpalli 50 Stone Road East. Guelph, Ontario, Canada.<amithn1997@gmail.com>

<sup>2</sup> Ashutosh 50 Stone Road East. Guelph, Ontario, Canada, N1G 2W1.<asingh47@uoguelph.ca>

<sup>3</sup> Syeda Tasnim 50 Stone Road East. Guelph, Ontario, Canada, N1G 2W1.<stasnim@uoguelph.ca>

**ABSTRACT** Agricultural production strongly depends on climate and weather. When the air temperature falls below 0°C, freezing may occur to sensitive crops, significantly affecting the crop production. For example, Ontario farmers reported that 88% of their apples were damaged in April 2012 due to frost. The main reason of this damage was the early blooming of the apple trees due to nice and warm weather in February and March, which caused the early freezing temperature to kill the apples by the frost. Some of these frost related losses can be prevented using a number of different methods. It is important for Ontario growers to be aware of these methods so that they can evaluate which methods are feasible and economical for combating frost damage. Therefore, the objective of the current study is to conduct a thorough review on different types of frost as well as frost protection methods. Active and passive methods will be looked at specifically, including their advantages, disadvantages, followed by a detailed review on mobile heating units. Another area of focus is the frost buster and frost guard systems, their advantages, and disadvantages in prevention of frost, as well as the feasibility of their use in Ontario orchards. Finally, this study will focus on improving the current frost protection methods. The study reveals that if the cropland associated with the frost damage is comparatively small and if the area is prone to low temperature the best frost protection method to be used should be frost guard. The study recommends that each frost protection method should be considered according to the farm specifications, weather conditions, and a thorough economic study considering labour and material costs. The use of an unmanned aerial vehicle (UAV) or the drone in addition to the use of frost buster or the frost guard would work better to prevent frost protection. Finally, a comparison between frost buster and other active frost protection methods are listed for Ontario growers to evaluate different methods in terms of feasibility and economic consideration.

**Keywords:** Frost Buster, Frost Guard, Frost, Phase Transition

**INTRODUCTION** Considering the temperature drop that always occur during the winters in Canada, it is understood that the crop yield will be affected with the frost damage (“Frost Damage in the Fall Vegetable Garden | Gardener’s Path,” 2019). Comparing the size of Canada with other countries, only 7 percent of the land is suitable for the farming purposes. In that small percent Ontario and Prairies shares the maximum area (“Crops |

The Canadian Encyclopedia,” n.d.). The plant suffers from frost damage as a result the yield is reduced and in turn loss occur in this sector (“Frost Damage in the Fall Vegetable Garden | Gardener’s Path,” 2019). The fruits, vegetables and the cash crops are those which suffer more from the freeze damage and propagates a huge loss to the growers (Lou et al., 2009).

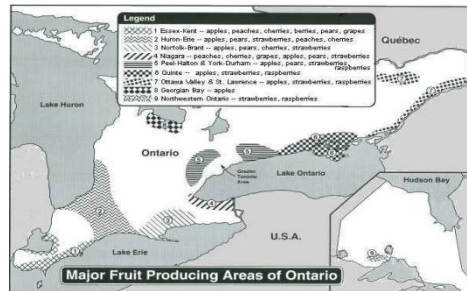


Fig 1 Major fruit producing areas of Ontario ( Glen R. Murray,2010)

Ontario has the correct and the best source of the weather and soil to grow a wide variety of crops, fruits and vegetables [3]. Hence the growers are able to grow a wide variety of tender crops, high quality fruits and vegetables. The most common ones include grapes, plums,cherries, pears, peaches, apricots, apples, hazelnuts, walnuts and nectarines. Figure 1 shows the major fruit producing areas in Ontario (“ONfruit,” n.d.).Frost has directly and indirectly causes damage to the crops, fruits and vegetables, the Australian growers are said to face a loss of over \$ 360 million every year (“Effect of Frost on Fruit Crops and Their Management,” n.d.). This is a huge loss and it affect a wide range of people for their daily food. The loss due to the frost damage is found to be the higher considering other natural hazards causing the crop damage (“Effect of Frost on Fruit Crops and Their Management,” n.d.).

Reports shows that Ontario lost about 88 percent of the apple grown. The frost has led to this devastating situation and it has given out a huge loss to the apple growers in Ontario. The main cause of this damage was the early blooming of the apple trees due to nice and warm weather in February and march, which caused the early freezing temperature to kill the apples by the frost (Jun 06, June 6, & 2012, 2012). when considering the frost bite to the fruits and vegetables, it is necessary to look at the temperature trends in Ontario, Fig 2 shows the data about the temperature trends in the years between 1920 and 2000 . The frost has caused a long list of losses to growers, it was reported that a large area of potato grown fields have reported frost damage, as the temperature went down to -5°C . so it is necessary to prepare the crop field to be able to protect the crops from the severe cold night. Here comes the need of various frost protection methods to save the crops ( Glen R. Murray,2010)

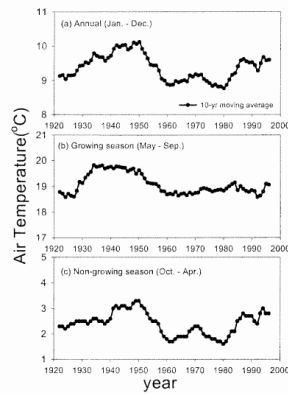


Fig 2 Temperature trend in Ontario between 1920 and 2000 (a) Annually (b) Growing season (c) Non-growing season ( Glen R. Murray,2010)

It is seen that different stages of plant life from the formation of the buds to the ripen fruit have different temperatures for the 10% and 90% kill. It is seen that buds tend to be more resistant to the freeze and the resistance increases as it goes to the preceding stage. Also it is seen that during then prolonged cold nights the bud hardiness occur to protect the buds from frost. But after that if the temperature drops then the bud hardiness tend to decrease (defieldsja, 2019).

Different types of frost occur when the temperature goes to the subzero temperatures. The main two types of frost that are responsible are advective freeze and radiation frost. Both these types affect the plants differently in terms of frost. So there is an importance to understand these types of frosts perfectly. Advective freeze – when the subzero temperatures occur due to the windy conditions or sometimes called as advective condition causes the damage to the plants. The winds may hit on a speed scale starting from 5 mph or more and will hit the plants and takes the heat from the surface of them, resulting in the freeze in the tissues and causing the plant to die. But these wind can be sometimes beneficial.

Pome Fruit – Apples

Apples	Silver Tip	Green Tip	1/2" green	Tight Cluster	First Pink	Full Pink	First Bloom	Full Bloom	Post Bloom
Old Temperature	-8.9	-8.9	-5.6	-2.8	-2.8	-2.2	-2.2	-1.7	-1.7
10% Kill	-9.4	-7.8	-5.0	-2.8	-2.2	-2.2	-2.2	-2.2	-2.2
90% Kill	-16.7	-12.2	-9.4	-6.1	-4.4	-3.9	-3.9	-3.9	-3.9

Showing 1 to 1 of 1 entries

Pome Fruit – Pears

Pears	Bud Swell	Bud Burst	Tight Cluster	First White	Full White	First Bloom	Full Bloom	Post Bloom
Old Temperature	-7.8	-5.0	-4.4	-2.2	-1.7	-1.7	-1.7	-1.1
10% Kill	-9.4	-6.7	-4.4	-3.9	-3.3	-2.8	-2.2	-2.2
90% Kill	-17.8	-14.4	-9.4	-7.2	-5.6	-5.0	-4.4	-4.4

Fig 3 : Temperatures at which 10% and 90% kill will be occurring in apple and pears (defieldsja, 2019)

Here the figure 3 shows the temperatures at which 10 % and 90 % kill that will be happening to the apple and pears during different stages of the growth.

Consider a windy condition where the speed is more than 5 mph, here if the ambient temperature is more than the critical temperature of the plant, then this wind can make the warmer air above the denser cold air to mix up each other and helps keeps the ambient temperature down below the critical temperature of the plant and hence

saving the plant. Radiation frost – The radiation frost is predominant frost in the environment and causes more damage to the plants. So these frosts are to be looked in to more seriously. This type of frost happens when the cold wind rushes in to the environment with the clear sky without clouds. When there is clear sky the temperature outside will be more cooler and the solid objects will have the tendency to give out heat or radiate heat to the environment causing the object to cool. The soil, rocks and even the plant do the same. Hence the plant loses the temperature, the temperature of the plant drops below the critical temperature, causing the plant to die (Evans, 2000).

Table: 1 (Evans, 2000)

Frost Type	Characteristics
Radiation	Clear; calm; inversion; temperature greater than 0°C during day
Advection	Windy; no inversion; temperature can be less than 0°C during day

The frost can be managed or avoided in a smaller quantity by slowly increasing the moisture and the tissue temperature. These small changes will help to reduce the damage of plants by the cold temperature. For designing a better system for frost management, it is necessary to analyze three important factors in the frost formation, i.e, critical temperatures, dew point temperatures and freeze conditions or two types of frost.

**FROST BUSTERS** The Frost buster is a machine that is mounted on the trailer which is situated on the back side of the tractor. The machine consists of fans and propane containers, the strong fan is driven by the powerful motor of the tractor. The air that is to be blown out to the plantation is heated up by burning propane gas. The frost buster is so-only developed to protect the plants suffering from the harsh cold climate.

While operating the machine to reduce frost the inlet air to the fan is heated up to 80 °C by burning the propane gas. The heated air is blown through the outlets of the machine there are two outlets for throwing out hot air, one on the right side and one on the left side. These air can reach up to 40-50 m from the blowers. So these are very effective hot air blowers which can protect the plantation from frost.

The frost buster works on the principle of phase change or phase transformation rather than raising the temperature above the critical value like most other machines available in the market do. Here the machine works towards preventing the formation of hoarfrost. It is known that hoarfrost are the biggest damage causing elements in the plants (“Frostbuster,” 2019.).

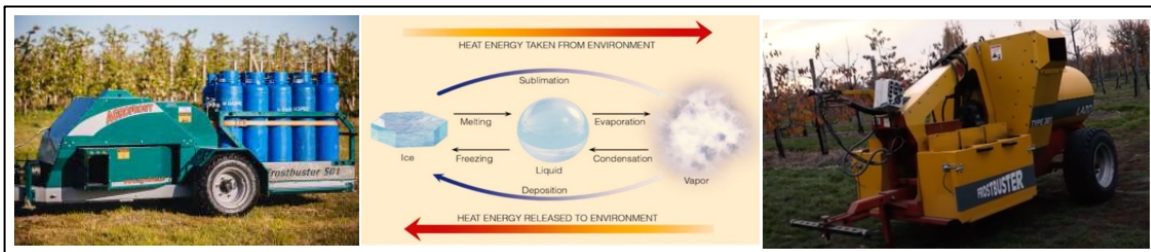


Fig 4 : The Frostbuster,Phase transition, First generation of the frost buster F301 (“Frostbuster,” 2019.)

The frost buster uses the hoarfrost formation as the source to supply the energy to the flowers or the buds to protect them from the devastating frost. Here in this situation what happens is that the vapour that is present in the atmosphere in the cold temperature turns to hoarfrost by means called as deposition or some times called as desublimation. So when this formation of this ice crystal (hoarfrost) happens, the energy is given out to the atmosphere, in this case to the flowers and the buds (majority of energy). so flowers and the buds get the energy to survive the frost but on the other hand if this hoarfrost is staying on for a long time, this may lead to the damage of the plant. Here the frost buster will control the hoarfrost formation as it turns the frost into vapour by supplying heat energy. The frost buster make sure that the hoarfrost will not stay on plant surface for too long. Then the temperature again goes down and again the hoarfrost forms which gives energy to the flowers, helping the flowers and the buds to survive (“Frostbuster,” 2019.).

There is three generations of frost busters available, the first generation of frost buster is the F300 and F301. The first generation of the frost buster was developed in the early 2000’s. The F300 is having two exits for the hot air to blow outside, one at the top side and the other on the down side. The F301 has a large fan which blows out the hot air with high force.






	Fan of the frost buster F301	The F301 has a large fan which blows out the hot air with high force.
	Bottle holder for F501	The F501 have universal bottle holder and it can accommodate any bottle ranging from 20-45 kg in weight
	Horse break safety valve	The bottles are connected with horses to transport the propane gas to the burner and every horse has a horse break safety valve which gets activated and shut down the gas flow immediately if any leak is sensed
	safety belt on propane tanks	There are safety belt available to hold the propane bottles in place when moving through the slopes and the bad roads.
	free wheel gearbox	Free wheel gear box with 30 % horse power margin is used. This gear box is directly connected to a fan impeller with an axle, with no moving parts in between.
	frame or chases of F501	frame is designed and build to handle a load up to 4000 kg
	single short angled PTO shaft	Used to connect the tractor with frost buster. One end of the PTO shaft is connected to the free wheel gear box of the frost buster and the other end is connected to tractor

Fig 5 : Frost buster F501 main parts (“Frostbuster,” 2019.)

There are two other types of frost busters, F152 and F252. Both these types are miniature forms of frost buster F501. The F152 and F252 is designed and developed to meet the demands of growers who have small orchids and vineyards. The F152 and F252 works in the similar working principle of F501, i.e., phase transition.

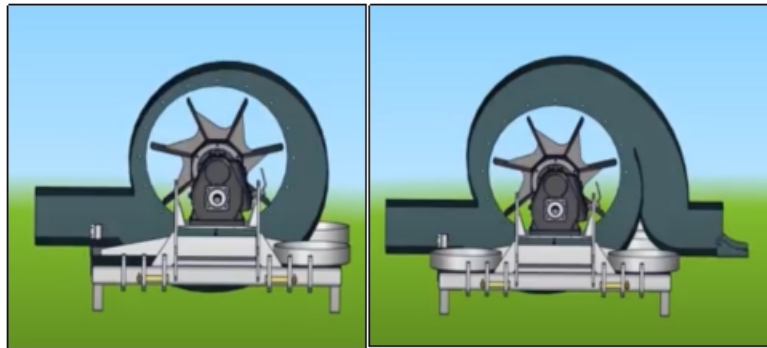


Fig 6 : Frost buster F152 and F252 (“Frostbuster,” n.d.)

The frame of F152 and F252 is designed to carry a load of up to 900 kg. Propane bottles of capacity ranging from 20-35 kg can be used in these frost busters and a maximum of 6 bottles can be used at a time. The F152 and F252 use a two speed gear box which is directly connected to the fan axle to reduce the number of moving parts and as a result to reduce the maintenance. These frost busters are similar in all way to F401 and F501, only that it is small sized (“Frostbuster,” 2019.).

**FROST GUARDS** Frost guard is developed for the demands of fruits, vegetable, small vineyards and small orchid growers. This has the capacity to protect fields up to one hectare. The frost guard is very easy to use and to transport, which has made the growers to buy it even for use in large fields. These machines are installed with easy auto start system which makes them more popular. These are used mainly in plastic tunnels and greenhouses. Frost guards were introduced in 2007 and in 2012 with the GC models. In 2016 the all new frost guard revolution was introduced. In 2018 the frost guard basic was developed (“FrostGuard,” 2019.).

The frost guard revolution is the best one with doors on all sides which are closed and is sound proofed. This will fight against the frost at night and gives a high positive output to the users. The frost guard was developed from the experience from the GC model, so it is more effective. The machine is not a heating system, it works on the principle of phase transition. This revolution consumes 30% less propane than the previous model with out compromising the frost protection efficiency. There are mainly three models in the revolution. R20 model has the exit pipe just above the ground level, R25 with exit pipe in the middle of the frost guard and finally R30 with the exit pipe on top. R20 models are used for high crops such as apples, apricots and cherry trees. For low crops such as strawberries and wines R25 models are used. R30 models are rarely used, they are used in some vines and cherries. The exit of the R30 can be angled accordingly in some field situated in slopes.

The revolution model is the best model in the frost guard. The three revolution models, i.e., the F20, F25 and F30 is shown in the figure 25. It is evident from the figure that all the tree are similar with their hot air exits on different levels (“FrostGuard,” 2019.).

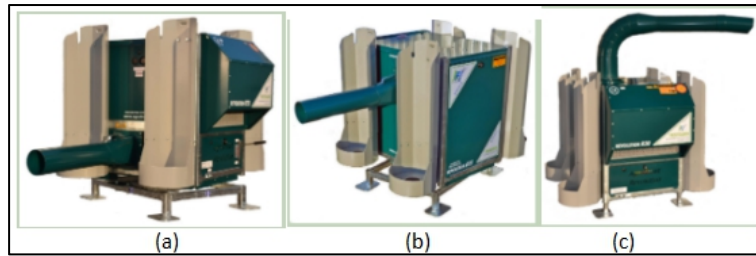


Fig 7 : (a) Frost guard F20, (b) Frost guard F25, (c) Frost guard F30 (“FrostGuard,” 2019.).

The revolution is completely enclosed with doors on all four sides and a panel on the top. All these sides can be opened separately. The frame of the revolution is made with galvanized steel and all the panels are sound proofed. The revolution uses a two cylinder 16 HP vanguard engine which is universally available. This engine is robust and delivers the required power.




	Vanguard engine	Two cylinder 16 HP vanguard engine which is universally available
	500 kg propane container	The revolution models can be connected with the gas bottle or a large container with a minimum capacity of 500 kg
	integrated bottle holders	An integrated heating system is used to heat the bottles with out being frozen up

Fig 8 : Main parts of frost guard (“FrostGuard,” 2019.)

The miniature and cost effective model of the frost guards are the basic. The basic is small in size and very cheap compared to revolution. The cost has been cut short but the safety is not all compromised in the basic.



Fig 9 : Frost guard basic model (“FrostGuard,” 2019.)

Similar to the revolution the Basic is also having three different models, B20, B25, and the B30 model. B20 is having the exit pipe below, B25 on the middle and B30 on the top.

The basic model is having 3 wheels and can be dragged by the grower to the desired spot. Unlike the revolution model the basic model is not completely covered. This model can be supplied with propane in a bog tank or propane in the bottles. Three propane bottles can be used at a time in the integrated bottle holders on the Basic. The basic model is made small as possible to store it easily and the weight is only 220 kg. The length of the machine is 140 cm. The basic is fitted with a one cylinder 14 HP propane engine. The basic is similar in every sense to the revolution and gives a good output. The basic uses the same pulse burner as the revolution. The basic can also be fitted with an auto start system. The basic revolves around its axis in 360° motion and it takes 8-9.5 minutes for the one complete tour. The intake air before being passed to the intake will be preheated by the engine, which in turn cools the engine down. This gives more efficiency for the machine. The basic is suitable for small fields and gives the appropriate results (“FrostGuard,”2019.).

Table 2 : Results given out by engaging frost buster for frost protection in four different farms (“Frostbuster,” n.d.),(a)R20 (b)R25 (c)R30 (d)B20 (e) B25 Technical data of revolution and basic model (“FrostGuard,” 2019.)

	Farm 1	Farm 2	Farm 3	Farm 4	(a)	(b)	(c)	(d)	(e)
<b>Engine (runs on propane)</b>					Briggs&Stratton Vanguard 16 HP mono-cylinder electrical starter	Briggs&Stratton Vanguard 16 HP mono-cylinder electrical starter	Briggs&Stratton Vanguard 16 HP mono-cylinder electrical starter	Greenpower 14 HP mono-cylinder electrical starter	Greenpower 14 HP mono-cylinder electrical starter
<b>Bodywork</b>					Completely closed	Completely closed	Completely closed	Open structure	Open structure
<b>Maximum capacity</b>					1 ha	1 ha	1 ha	1 ha	1 ha
<b>Dimensions mm</b>					1200x775x1200	1200x775x1200	1200x775x1200	1300x800x1200	1300x800x1200
<b>Weight</b>					325 kg	325 kg	325 kg	218 kg	218 kg
<b>Average gas consumption</b>					10.5 kwh	10.5 kwh	10.5 kwh	10 kwh	10 kwh
<b>Air distribution</b>					machine intakes	machine intakes	outlet intakes	machine intakes	machine intakes
<b>Auto Start</b>					Option	Option	Option	Not available	Not available
<b>Wheels</b>					No	No	No	3 wheels	3 wheels
<b>Bottle holders</b>					Possibility to mount 4 pcs	Possibility to mount 4 pcs	Possibility to mount 4 pcs	Possibility to mount 3 pcs	Possibility to mount 3 pcs
<b>Transportable with gas bottles in the holders</b>					Yes	Yes	Yes	No	No
<b>Minimum temperature</b>	6.8 °C	-2.2 °C	-6.1 °C	-6.4 °C					
<b>Number of hectares</b>	5	9	9.3	12					
	protected	126.4	127.8	91	10.1				
<b>Number of fruits per tree</b>	unprotected	93.8	91	44.8	98.4				
	difference	852 %	59 %	180 %	12.8 %				
<b>% damaged fruit</b>	protected	7.1 %	5.3 %	1.9 %	6.75 %				
	unprotected	26.2 %	69 %	64.4 %	24.5 %				
	difference	-73 %	-89 %	-88 %	-64 %				
<b>number of good fruits</b>	protected	117.4	130.8	98.2	71.3				
	unprotected	12.4	97	40.8	12.3				
	difference	847 %	112 %	139 %	38 %				

**LITERATURE REVIEW** Chantre et al. Came to the understanding that to improve the crop yield and quality of crops a certain pathway must be followed which may take over a long period of time. The process may involve advance modification and learning processes.so it is understood that frost protection will be entirely possible with atmost efficiency only if a long time researching is done [14].Author came up from their studies that each year new modifications are done by the farmers for improving their yield (Meynard, Dedieu, & Bos, 2012).The population increases day by day and the yield of crops should be in line with the population increase to prevent food shortages (Long, Marshall-Colon, & Zhu, 2015). The frost has adversely affected the supply chain and the jobs in the agricultural sector, this led to a great economic loss (Snyder & Melo-Abreu, 2005).There are a lot of researches going in this field for reducing the frost but Rodrigo et al. found that it is still the major source of loss in the field of vegetable and fruits production (Rodrigo, 2000). Given that the frost causes devastating and cruel results to the farmers who depend on their productivity, it is understood that the frost have been prevented by the usage of wind machines. The wind machines are the oldest and effective source of active frost protection method adapted by the farmers (*Wind Machine Induced Changes in the Nocturnal Microclimate of a Citrus Grove*, n.d.),(Reese & Gerber, 1963).Villalobos et al. found that irrigation protects the crops from the frost by releasing heat by water cooling, which is about  $4.18 \times 10^{-3}$  MJ/K/kg, and by water

freezing which gives 0.334 MJ/kg of heat to the crops. The irrigation process is done by the use of sprinklers so that there is always a thin layer of water over the ice so that the ice does not take energy from the crops, hence protecting the crops from the harmful frost damage (Villalobos & Fereres, 2016). The common frost protection methods used by the growers are by using sprinklers for irrigation, heating units for temperature inversion, wind machine for mixing heated and cold air. According to him these are inefficient and requires more input. Here he suggest using unmanned aerial vehicle (UAV) for the frost protection. These machines are also called as drones. These drones will detect the temperature of the orchids during the cold night and in turn give signals to the robots in the ground in which heaters are mounted. The robot will heat those orchids suffering the most and thus preventing the frost damage in them with minimum energy use (Chuck Gill, 2019).

Table 3 : Automated frost protection method (Chuck Gill, 2019).

Year	Protection Method	Alarm System
1984	Manual trigger of wind machine, Sprinklers, Heaters	Temperature sensors, Bedroom alarm
2008	Artificial Smoke	Temperature sensors, Fuzzy controller
2009	Sprinklers	Thermistors
2009	Electrical heating cable	Air temperature sensors, Timer switch
2012	Artificial cloud burner	WSN temperature sensors, Fuzzy controller
2017	N/A	WSN Temperature sensors, Public weather forecast service
2019	N/A	WSN sensors, Weather station service, Multivariate index
2019	N/A	WSN sensors, Weather station data

The Lazo frost guard that is made in Belgium is cheaper than the wind machines that are used in the farm to prevent the frost in crops. The Lazo frost buster was able to raise the temperature by 2 ° C to 7 ° C within a field area of about 1ha [24]. The sprinklers are the best source to control the frost damage in the plants, Barfield et al. studied about the heat convection mechanism and calculated the efficiency attained while using water to prevent frost by using the sprinklers (Barfield, Walton, & Lacey, 1981). The air disturbance technology to prevent the frost formation in plants. Here while focusing on the working principle and selection criteria, it was found that this technology provided long lasting frost protection with better efficiency and effectiveness. This technology focused on using wind machines, selective inverted sinks and frost protection helicopter for creating air disturbance. Initial cost was high which is unsuitable for many small scale growers (Hu et al., 2018). Automation of frost protection were familiar from the 1980s, Tested the usage of temperature sensors and bed room alarm for automating the frost protection. When the temperature in the farm reaches a certain temperature were the crops start to get frozen up, the temperature sensor senses it and activates the bedroom alarm that act as the activator and alert the grower to turn on the frost protection machine (*Value of Weather Information: A Descriptive Study of the Fruit-Frost Problem*, n.d.).

Automated frost protection saves time and effort. It uses sensors and predictions from the weather data to serve the crops. The effort to automate the frost protection has started from 1984 and still continuing until now. The sensors have advanced over the years, now being the wireless sensor networks (WSN). these wireless sensor senses the temperature and the weather data to start up the frost protection machines.

**DISCUSSION** Frost damage in crops has always posed a great amount of risk and losses for the growers. The passive frost protection for the crop may be useful only for some crops, in a small crop area. The active frost protection methods are the main techniques that prevent the frost from damaging the crops in a large amount of area and is the most effective and efficient. When there is a sudden warning of the frost, active methods are the best way to protect the crops from the devastating frost. The frost buster is the best source to prevent frost from damaging the plants. It is understood that the frost buster can protect the crop field of area of 10-12 ha. This mobile heating unit is efficient and gives all the growers the expected performance. Whenever the frost buster moves through the crop field the temperature of the crop is measured to be 15-20°C. the frost buster works on the principle of phase transition which is the best method to prevent the frost formation in the crops. The frost guards are also the similar version of the frost buster but is more suited for the smaller field area and cost effective than the frost buster. These are the best in market mobile heating units with years of experience. The table 6 gives the idea of the active frost busters and their advantages and disadvantages in the brief format.

The frost busters and the frost guard is the best technology that is efficient in preventing frost in crops. The combination of active frost protection were studied and has given out great results for the growers. According to Martsolf the combination of wind machine and heaters gives high effective results than either of them used alone for the frost protection [32]. Brooks came to the conclusion that if one wind machine and 50 heater were used per hectare of land, it gives similar effect of using 133 heaters per hectare of crop land [33]. The combination of heaters and wind machine were cheaper by 53% and 39% over the years when operated for 100 and 50 hours respectively. Also in California the combination has protected the citrus orchids, when the temperature went down up to -5°C, only half the number of heaters were needed for the protection thanks to the wind machine (Angus, n.d.). Evans came to the conclusion that if 25-50 heaters per hectare are placed on the periphery of the crop field in combination with wind machine can save up to 90% of the fuel as the frost can be control by wind machines in the mild weather condition and heaters need not operate in those condition (Evans, 1999). Martsolf reported in his survey that a grower used the combination of heaters with sprinklers and turned out to be beneficial. This combination prevents the formation of ice crystals over the crops. He used a cover to prevent the water from blowing out the flame. The heaters are started first and sprinklers are only started up when the temperatures go very low (*Effectiveness of Orchard Heaters / Robert A. Kepner., n.d.*).

Frost buster and frost guards are very effective heaters and is useful in protecting the crops from the disastrous frost. This machines when coupled with other active frost protection method will help in completely eliminate the frost in the plant. This mobile

heating unit when paired with sprinkler can help from frozen up by the devastating cold nights.

Table 4 : Various active frost protection methods, its advantages and disadvantages (Effectiveness of Orchard Heaters / Robert A. Kepner., n.d.).

ACTIVE PROTECTION METHOD	ADVATAGES	DISADVANTAGES
Sprinklers	Less labour requirement, low operational cost.	High installation cost, wind drift may effect the performance, high volume of water required.
Wind machines	Fuel usage is efficient.	High wind condition may cause the fan to fail, high initial cost, creates noise.
Helicopters	Air inversion is created in a large area with less time.	Operational costs are very high.
Heaters	Low installation cost.	High labour requirements, maintenance are costly, fuels are expensive.

From there referred reviews it was found that the drone (UAV) system in connection with mobile heating units i.e; the frost buster and frost guard can be used in the frost prevention method to give out more accurate desired result. These system can be economically feasible than the old methods like wind machines and other liquid fueled heaters.

**CONCLUSION** It is understood that there are different varieties of active frost protection methods ranging from the simplest ones to the sophisticated ones are available in the market. The effective performance of each of them is proportional to the area of the crop land, worth of the crop and the climatic factors. If the crop land associated with the frost damage is comparatively small and if the area is prone to low temperature very often then the best frost protection method to be used should be frost guard. It will prevent the orchids from the harmful damage. Each of the method should be considered according to the farm specification and its merit to the farm should be determined, a thorough calculation on the economic factors must be also be done before using it in the farm to make sure it is feasible. The frost buster and frost guard has years of experience in the frost protection and its been adopted by the growers since then. Although there are many other cost effective methods available in the market, those methods are not efficient enough to give out the desired result. The frost

buster and the frost guard if coupled with wind machine or the sprinklers can be a great step up in the cost reduction aspect, but needs more attention to be given in their research. In the future it is possible to witness combination of frost buster and other active frost protection methods. The combination of UAV with frost buster or frost guard is also suggested. UAV or the drone can be connected with frost buster or the frost guard so that the entire process can be automated, when the temperature of the certain area of farm land gets affected by the colder wind the drone sends signals the frost buster the exact co-ordinates of the farm land and hence the frost buster can heat up the area. Currently the frost buster or the frost guard is controlled manually by using tractor. But these can change in the future creating a well controlled automated frost protection mobile heating unit.

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## REFERENCES

Angus, D. E. (n.d.). *Frost Protection Experiments Using Wind Machines*. 47.

Archived—Climate Change Action Plan. (n.d.). Retrieved April 14, 2021, from <https://www.ontario.ca/page/climate-change-action-plan>

Barfield, B. J., Walton, L. R., & Lacey, R. E. (1981). Prediction of sprinkler rates for night-time radiation frost protection. *Agricultural Meteorology*, 24, 1–9. [https://doi.org/10.1016/0002-1571\(81\)90029-7](https://doi.org/10.1016/0002-1571(81)90029-7)

Crops | The Canadian Encyclopedia. (n.d.). Retrieved April 14, 2021, from <https://www.thecanadianencyclopedia.ca/en/article/crops>

defieldsja. (2019, May 2). Stone Fruit Update. Retrieved April 14, 2021, from ONfruit website: <https://onfruit.ca/2019/05/02/stone-fruit-update/>

Effect of Frost on Fruit Crops and their Management. (n.d.). Retrieved April 14, 2021, from <https://www.biotecharticles.com/Agriculture-Article/Effect-of-Frost-on-Fruit-Crops-and-their-Management-3761.html>

*Effectiveness of orchard heaters* / Robert A. Kepner. (n.d.). 41.

Evans, R. G. (1999). *Frost Protection in Orchards and Vineyards*. 20.

Evans, R. G. (2000). *The Art of Protecting Grapevines From Low Temperature Injury*. 13.

Frost Damage in the Fall Vegetable Garden | Gardener's Path. (2019, November 14). Retrieved April 14, 2021, from Gardener's Path website: <https://gardenerspath.com/how-to/beginners/frost-damaged-vegetables/>

Frostbuster. (n.d.). Retrieved April 14, 2021, from Agrofrost nv website: <http://www.agrofrost.eu/frostbuster/>

FrostGuard. (n.d.). Retrieved April 14, 2021, from Agrofrost nv website: <http://www.agrofrost.eu/frostguard/>

Hu, Y., Asante, E. A., Lu, Y., Mahmood, A., Buttar, N. A., & Yuan, S. (2018). Review of air disturbance technology for plant frost protection. *Biol Eng*, 11, 9.

Jun 06, C. C. · C. N. · P., June 6, 2012 9:03 AM ET | Last Updated:, & 2012. (2012, June 6). Damage to Ontario's apple crop is worse than expected | CBC News. Retrieved April 14, 2021, from CBC website: <https://www.cbc.ca/news/canada/hamilton/headlines/damage-to-ontario-s-apple-crop-is-worse-than-expected-1.1202483>

Long, S. P., Marshall-Colon, A., & Zhu, X.-G. (2015). Meeting the Global Food Demand of the Future by Engineering Crop Photosynthesis and Yield Potential. *Cell*, 161(1), 56–66. <https://doi.org/10.1016/j.cell.2015.03.019>

Lou, W., Qiu, X., Wu, L., Ni, H., Tang, Q., & Mao, Y. (2009). Scheme of Weather-Based Indemnity Indices for Insuring Against Freeze Damage to Citrus Orchards in Zhejiang, China. *Agricultural Sciences in China*, 8(11), 1321–1331. [https://doi.org/10.1016/S1671-2927\(08\)60344-2](https://doi.org/10.1016/S1671-2927(08)60344-2)

Meynard, J.-M., Dedieu, B., & Bos, A. P. (2012). Re-design and co-design of farming systems. An overview of methods and practices. In I. Darnhofer, D. Gibbon, & B. Dedieu (Eds.), *Farming Systems Research into the 21st Century: The New Dynamic* (pp. 405–429). Dordrecht: Springer Netherlands. [https://doi.org/10.1007/978-94-007-4503-2\\_18](https://doi.org/10.1007/978-94-007-4503-2_18)

ONfruit. (n.d.). Retrieved April 14, 2021, from ONfruit website: <https://onfruit.ca/>

Reese, R. L., & Gerber, J. F. (1963). *FIELD TRIALS WITH A WIND-MACHINE IN A CITRUS GROVE*. 6.

Rodrigo, J. (2000). Spring frosts in deciduous fruit trees Ð morphological damage and lower hardiness. *Scientia Horticulturae*, 19.

Snyder, R. L., & Melo-Abreu, J. P. de. (2005). *Frost protection: Fundamentals, practice and economics*. Rome: Food and Agriculture Organization of the United Nations.

*Value of Weather Information: A Descriptive Study of the Fruit-Frost Problem*. (n.d.). 13.

Villalobos, F. J., & Fereres, E. (Eds.). (2016). *Principles of Agronomy for Sustainable Agriculture*. Cham: Springer International Publishing. <https://doi.org/10.1007/978-3-319-46116-8>

*Wind machine induced changes in the nocturnal microclimate of a citrus grove*. (n.d.). 231.