Evolution of Freeze and Frost Protection Continues with Infrared, Electromagnetic Technologies

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THE PROTECTION OF VINEYARDS FROM frost and freeze events is an important consideration for vineyard managers in many different regions. To help growers cope with cold temperatures, a new technology, Frolight's infrared emitter-based grape bud and trunk protection device, is now available in the United States.

However, before that innovation is discussed, it's important to understand the definitions of a frost and freeze, to review the methods and systems that are currently in use, and to investigate different methods of modifying heat transfer to protect and moderate the plant physiological processes from harm.

Advective heat transfer and radiant heat transfer will be considered as well as the new method of electromagnetic heat transfer in vineyards. It will be valuable to review some of the terminology that will be used here and are covered in the three references used throughout this review.[1,2,3]

Frosts and freezes are in many ways very similar, and the following two paragraphs are the best short descriptions of the two events that I have found.

"A 'frost' is the occurrence of an air temperature of 0° C or lower, measured at a height of between 1.25 and 2.0 m above soil level, inside an appropriate weather shelter. Water within plants may or may not freeze during a frost event, depending on several avoidance factors (e.g. supercooling and concentration of ice nucleating bacteria). A 'freeze' occurs when extracellular water within the plant freezes (i.e. changes from liquid to ice). This may or may not lead to damage of the plant tissue, depending on tolerance factors (e.g. solute content of the cells)."

Comparison of Frost Protection Systems

		Min Frost Temp Protection	Advection Frost vs Radiation Frost	All Weather Protections	Both Advection vs Radiation Frost	No Night Labor	Direct Emission	Requires Permit	Full Automation	Protection Certainty
A	Fire, Candles, Chimney	25.7° F -3.5° C	✸	✖	✸	✖	✖	✸	✖	✖
B	Frolight Systems Grid (B1) Generator (B2)	21.2° F -6.0° C	✸	✸	✸	✸	✸ (B 1) ✖ (B 2)	✸	✸	✸
C	Heat Blowers	24.8° F -4.0° C	✸	✖	✸	✖	✖	✸	✖	✖
D	Electrical Tracing	25.7° F -3.5° C	✸	✖	✸	✸	✸ (D 1) ✖ (D 2)	✸	✸	✖
E	Helicopter	24.8° F -4.0° C	✖	✖	✸	✸	✖	✖	✖	✖
F	Irrigation	17.6° F -8.0° C	✸	✸	✸	✖	✖	✸	✸	✸
G	Wind Turbine Grid (G 1) Generator (G 2)	24.8° F -4.0° C	✖	✖	✸	✸	✸ (G 1) ✖ (G 2)	✖	✸	✖

Note: Wind turbine, Electrical Tracing and Frolight emitters operate on both diesel generators and grid based power and therefore have different CO_2 emission standards based on the source of power.

TABLE 1 Most previous systems of frost and freeze protection have relied on either transporting or adding sensible heat from the environment to the vineyard location where protection is needed. Frolight transmits its energy directly from the emitter to the grapevine bud or vine trunk, without heating the air.

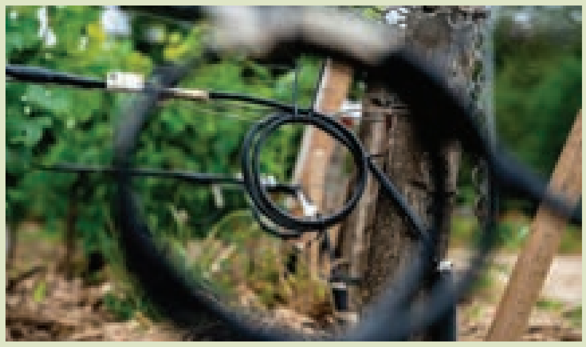
FIGURE 1 EXAMPLES OF FROST PROTECTION EQUIPMENT


Candle Smudge Pot (A)

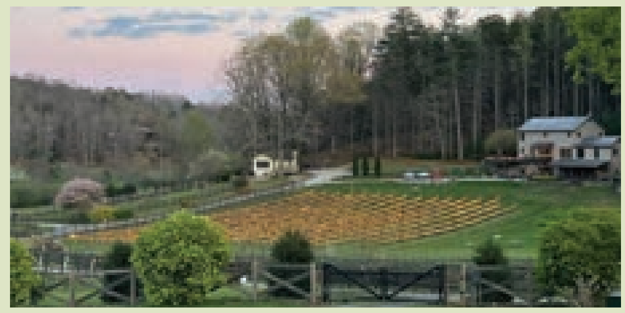

Propane Heater (B)


Wind Machines (C)


Sprinkler Irrigation (D)


Heat Trace Wire (E)


Helicopter (F)


Infared Emitters (G)

"A frost event becomes a freeze event when extracellular ice forms inside of the plants. Freeze injury occurs when the plant tissue temperature falls below a critical value where there is an irreversible physiological condition that is conducive to death or malfunction of the plant cells. This damaging plant tissue temperature is correlated with air temperatures called 'critical temperatures' measured in standard instrument shelters. Subzero air temperatures are caused by reductions in sensible heat content of the air near the surface, mainly resulting from (1) a net energy loss through radiation from the surface to the sky (i.e. radiation frost); (2) wind blowing in subzero air to replace warmer air (i.e. advection frost); or (3) some combination of the two processes."[1]

These definitions are important to keep in mind as we review and compare the technologies of frost protection so that vineyard managers can make decisions about the best practices for their particular vineyard while comparing the cost benefits of each practice.

Categories of Protection

PASSIVE ELEMENTS

There are many passive methods to minimize frost events and reduce the possibility of plant damage. Selection of vines with biological, natural resistance to frost events is an important starting point, as is the selection of the site for the vineyard, and then the modification of that site, if necessary, to help drain cold air away from the target zone. Poking a hole in a cold bowl is one of the most cost-effective elements to protect a cold zone. Trees can act as a dam that blocks the cold air from flowing away quickly and allowing

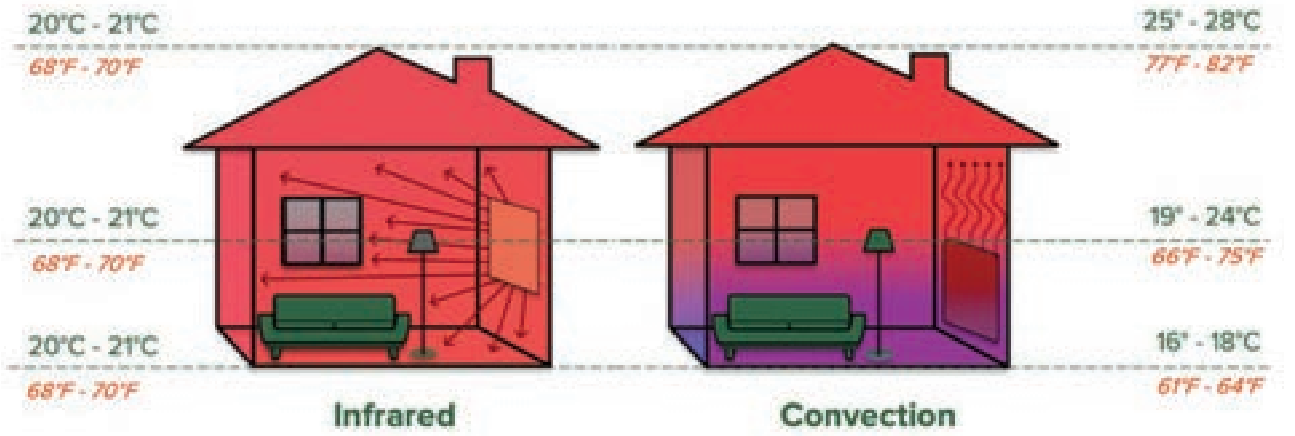


FIGURE 2 Infrared radiation (left) heats objects directly, and not the air between the heat source and the object to be warmed. On the right, convection heating (sensible warming) heats the surrounding air in a confined space.

warmer air from above to move in. Maintaining a good nutritional status of the vines can give as much protection as the plant can naturally withstand.

Removing cover crops upslope can provide a small but potentially important temperature buffer. Bare ground can be about 0.5° C warmer than ground with grass or other plants. Irrigation of vineyards will fill void spaces in the soil and increase the heat capacity of the surrounding area and is recommended to be irrigated at about field capacity for best results. If a grower chooses irrigation, covering the rows with clear plastic sheeting will magnify the heat capacity of the soil, adding radiant energy to the environment. Finally, controlling ice nucleation active (INA) bacteria can reduce the impact of ice induced damage in plant tissue. There are non-INA bacteria that can out compete these INA bacteria as well as copper-based pesticides.

ACTIVE ELEMENTS

In this article, **TABLE 1** compares active elements in frost protection systems.

HEATERS

One of the oldest methods for frost protection are heaters, the first of which were simple fires or candles placed in the rows (**FIGURE 1A**). These fires were easy to place, but they weren't very efficient and soon evolved into stack heaters. In this heater type, fuel is burned in a container with some chimney height. The fire heats the "stack" so that not only does the heat rise to create the airflow to draw the cold air away from the vines, but the stack also emits radiant energy. However, if there is too much wind or there's no inversion layer, the heat loss will be too great for heaters to keep up with cold air replacing the heat lost to the sky. Vine heat losses on a radiation frost night have been estimated to be within the range of 10 to 50 W m^{-2}, whereas the heater energy ranges from 140 to 280 W m^{-2} depending on the fuel and the number of heaters. Thus, most of that sensible energy rises and is not available to the vines. This indicates that either the number of heaters should be moderated to equal the loss from the vineyard, or the heat generated by heaters should be lowered.

The quandary is to match the up flow of heat to the draw in of cold air that replaces the rising heat to the inversion layer. It is obviously too expensive in fuel to heat the whole of the inversion layer to counter the cold because it is not a confined space. Heater placement in upwind locations is a more effective solution. With energy prices increasing, there is significant effort to find fuels that transfer their energy more efficiently and heaters that require less labor to install and to service. Propane has become a fuel of choice in many places, but it is important to have systems in place for severe events to minimize propane tanks freezing when there is a rapid depletion of fuel (FIGURE 1B).

WIND MACHINES

Wind machines can significantly reduce the cost of fuel required to provide frost protection equivalent to fuel oil/propane heaters. However, there is a significant capital investment, as a single machine costs $40,000 or more. There are obvious labor cost savings with wind machines, and there can be more savings and less air pollution if the machine can be powered electrically. Growers should determine if the inversion layers in their location are at least 1.5° C or higher in the 2 to 10 m above the vineyard floor on most frost nights (FIGURE 1C).

While one wind machine can protect an 8-to-10-acre vineyard, it is highly dependent on the topography of the vineyard. Furthermore, the effectiveness of the wind machine decreases with the inverse square of the distance from the tower. This suggests that some overlap of placement is needed to provide a layer of increased protection on the boundary of each machine on larger blocks. Other factors to consider include how the use of a wine machine should be managed. Growers must account for the frequency of wind velocities greater than 5 mph (8 kmh), especially if there is supercooled fog. This event can cause icing on the wind blades with possible catastrophic results.

As a side note to wind machines, there has been some increased interest in vertical blowing blades to transfer the colder air upward to mix with the inversion layer. As of this reporting, studies of this type of implementation of wind machines have not shown good results.

SPRINKLERS

Overhead sprinklers, under canopy sprinklers and drip irrigation can be used to protect vines from frost events (FIGURE 1D). There are many reasons why this method is not very common in vineyards. A significant factor in many areas is water conservation, and using this method where water is limited is not advised.

If water is available, it can be used for frost protection due to the phenomenon of the heat of fusion. This is the property of water that as it freezes, it releases some heat, which for frost events can be useful for a short timeframe. However, if the temperature rises fairly quickly, the reverse happens. When water converts from ice to water, it cools the surrounding environment with its latent heat of fusion. Another way to use water is to micro-spray the ground and incident radiation from the sun can then heat the air above.

However, water is often not used for vineyard frost protection. When water freezes on the vine, at first it can provide some insulative properties, but the weight of ice on the vines can have negative destructive effects by breaking canes and buds if not applied carefully.

ELECTRICAL TRACING

Electrical tracing is not often used in this country, and even where it is used, it has been shown to be quite expensive and not very effective (FIGURE 1E). This method uses an electrical wire heated by an electric current. This method produces sensible heat, which is not very effective for grapevines. Its heat production cannot be targeted to the appropriate zone where heat is desired without harming plant tissue by overheating.

HELICOPTERS

The cost of helicopters is the major factor limiting this method of frost protection (FIGURE 1F). Additionally, as with wind machines, supercooled air with the mechanical shock of the down draft can initiate ice crystal formation. They are also ineffective if there is no inversion layer. They can be useful when other methods break down.

Electromagnetic Frost Protection

Laurens Devos and his business partner Alexander Schmidt founded the Belgian company Frolight in 2019 to produce the first infrared emitter-based grape bud and trunk protection devices. They came up with the idea that the most efficient way to protect grapevine buds and trunks would be to use an infrared beam aimed at the buds and trunks of grapevines because of all the other systems that were based on sensible heat transfer (FIGURE 1B). To raise the latent heat in a grapevine, a device must send some form of heat that keeps a grape bud or trunk above its critical temperature by keeping the vine tissue warmer than when tissue damage occurs. Frolight is now distributed in 10 countries with hundreds of customers using the system. Innovin Solutions is their distributor in the United States.

Air, or any gas, is notoriously inadequate in transferring heat. Water (and other liquids, wood or metals) are much better because the molecules are much closer together and, consequently, the efficiency of heat transfer is much better.

Fortunately, electromagnetic radiation is very efficient at transferring energy. Just look at our sun! Ninety-three million miles away, we can feel the heat of the sun on our faces when we walk outside. That heat is mostly from infrared radiation. Whether it’s cloudy, windy, rainy, or dry, infrared radiation penetrates your skin, and you feel warm inside, but not so much on your skin surface. Electromagnetic radiation excites molecules by making them vibrate more quickly. The more quickly they vibrate, the more they warm up. The infrared wavelength was chosen as the Goldilocks wavelength because of the relatively gentle effect of warming at lower power per emitter. Humans can’t “see” infrared, and UV would cause molecular breakdown. Visible light could work but would be obnoxious to work with, and longer wave lengths than infrared would not be as effective at warming at low power and would interfere with other transmissions.

The system works much like Christmas tree lights, in that a string of infrared emitters is embedded with a few visible lights to let you know when they are on (FIGURE 2). This string is attached to the fruiting wire of the trellis. According to Mark Darley, owner of All Angels Vineyard in Berkshire, England, if using VSP spur pruning, then placement is right on the fruiting wire, which protects the primary buds (FIGURE 3). However, if cane pruning and most of the critical buds are below the fruiting wire, the string might need to be suspended to the bud target zone. In either case, if there is risk of trunk damage, the string can be run down the trunk and up the other side to provide protection of the trunk.

Strings come in a variety of lengths to suit a row length of up to 656 feet per row (FIGURE 4). It is important to know that unlike Christmas tree lights, if there were ever a problem with an emitter, a single one-meter length would not light up with the visible light string. That section can be removed and patched back into the main string. The strings are installed prior to budbreak, so they are ready for protection during the frost season. The strings are attached to the trellis with a taping device. Once proficient in the work, a two-person crew can install an acre in one half day.

FIGURE 3 Frolight tubes are attached to the fruiting wire for VSP-trained vines. Cane pruning and other systems may need to be attached in a zone close to the buds that the grower wants to protect.

POWER IN THE STRINGS

There are a variety of ways the strings can be powered and a wide variety of choices that can be implemented to suit individual vineyard needs.

The system has a main controller that can control up to 1,200 meters of emitters. After that, there are "slaves" that can be added to control incremental additions to the system. The most efficient voltage is 480 three phase. At this voltage, a system consumes about 15 watts per meter. With the 480 three phase system, each leg runs one string at 277 volts with a neutral connection.

If grid power is available, it can be the least noisy and possibly least expensive way to run a system. If needed, Innovin Solutions, the US distributor of Frolight, can arrange to rent generators to supply vineyards that do not have grid connections, or if they cannot find a local generator that can be rented.

SYSTEM CONTROLS

Like the controls for wind machines, the controls of the infrared strings can be automated to turn on either through grid power or generator power once a target temperature set by the grower is met. It's important to note that infrared is not affected by wind or rain. There is no sensible heat emitted because the electromagnetic radiation warms the molecules of the denser plant material more effectively than the air. It is the internal temperature of the plant material that is protected, not necessarily the surface of the plant material, that is cooled by the ambient air temperature.

TRIAL SYSTEMS

For this article, I talked with six wineries who have trialed the Frolight system, and all found that the system worked in their vineyards as they expected. None of the US based vineyards had a significant frost event this year, as temperatures ranged from about 29° F and up. While one Virginia vineyard declined to be identified, five participants in the project included: Richard Woolley, winemaker and owner of Weathered Vineyards in New Tripoli, Pennsylvania; Thijs Verschuuren, vineyard director and biodynamic specialist at Hermann J. Wiemer Vineyards in Dundee, New York; Mark Diehl, winemaker and owner of Stonewall Creek Vineyards in Tiger, Georgia; and Peter Seifarth, owner and founder of Crane Creek Vineyards in Young Harris, Georgia.

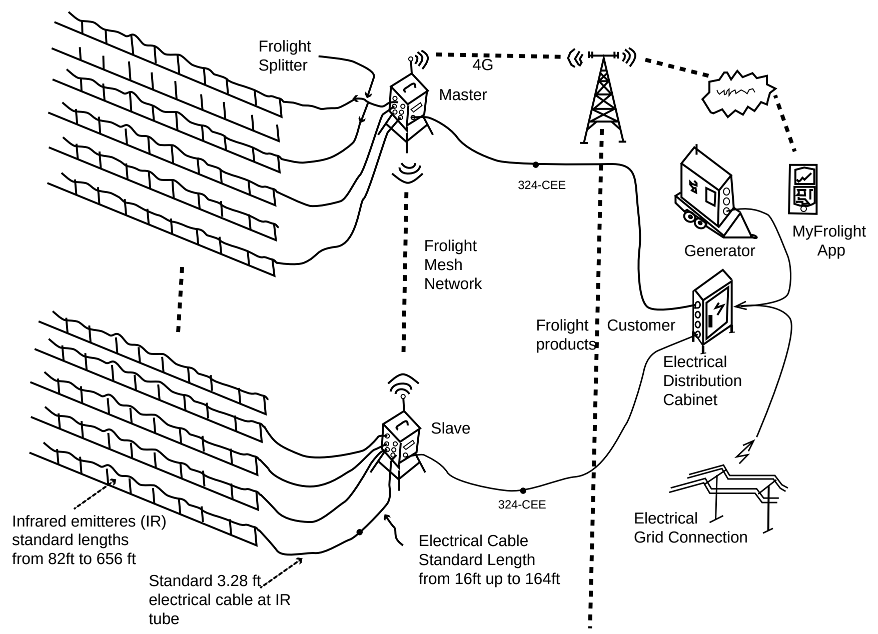


FIGURE 4 This diagram shows a typical layout schematic for Frolight frost and freeze protection of grapevines using either grid power or generator power. The general layout shows one master controller that is attached to the power distribution system. This controller can automate the protection cycle for multiple slave controllers.

Both vineyards in Georgia have had good experiences both in the ease of set up, and the functionality of the Frolight system. I then reached out to Mark Darley at All Angels Vineyard, who did have temperatures in the 28° F zone, and the Frolight system adequately protected his crop from frost damage. All vineyards indicated that they will likely purchase a system.

There are many variables that can be evaluated to determine a final cost estimate for this system, but Frolight has offered some guidelines for estimating the cost of a system. One issue is the number of plants per block, and a second is that wider-spaced rows make a difference on length of emitter strings per acre. Frolight has developed a rule of thumb that it costs about $6.80 per meter for grid powered systems and $6.20 per meter for generator powered systems.

In conversation with those testing out the Frolight system, several vineyard managers indicated that they may determine their worst location that needs amelioration from weather conditions and use that acreage as their starting point. Additional blocks would be added as the return on investment proves that the Frolight system is worth its installation cost.

Return on Investment

The advantages I see in the Frolight system are the tangible results in effectiveness in areas where other systems have not been able to help vineyards in the past. Modification of plant tissue in the open environment is not a simple task. Wind machines are expensive devices and do not work well when no inversion exists as well as when rain is part of the mix. The table of system comparisons outlines the conditions under which each type of system performs. The study Frolight conducted on their return on investment considered grid power versus locally generated power. In the end, the difference in pay back rate increases based on the percent crop lost annually (FIGURE 5).

This figure includes a graph and a table with information about the investment payback from using a Frolight system. The graph annualizes the payback calculation, which begins earlier for grid connected systems than for fuel powered generators, assuming there are no significant initial grid costs to deliver power to the vineyard. There are sites where the grid infrastructure expense has to be taken into account. The calculations assume that over a seven-year period of time, 5%, 7.5% or 10% of crop is lost to frost/freeze damage with no frost protection. To evaluate whether a particular location is right for installation of Frolight, current mitigation methods must be taken into consideration and the savings or extra losses estimated

If the difference between doing nothing and your current method of frost protection averaged over 7 years is 10%, that number should be compared to the number that the Frolight system would expect to decrease that loss. For example, with wind machines that would include events where there was no inversion, or it was too windy. For this calculation, one also must look at historical weather events to find out how many events fall below the protection level of your current equipment's capacity or regions of a vineyard that the equipment does not protect as well.

The final element of total payback that must be considered in the difference between generator power and grid power, is the cost from the utility company to make the appropriate power drop and the amount of power that a location must agree to consume for that drop.

Conclusion

This technology has great potential to provide a much-needed increased level of safety by offering a lower freezing temperature that can be protected against. One might even see that crop protection insurance rates could drop with the increased level of protection afforded by Frolight, once proved by longer term use of the equipment. Regardless of that happening, lowering crop loss is a good thing. From initial reports, it is certainly a system that needs to be considered as an important addition to producing quality wines from grapes grown in difficult locations. WBM

References

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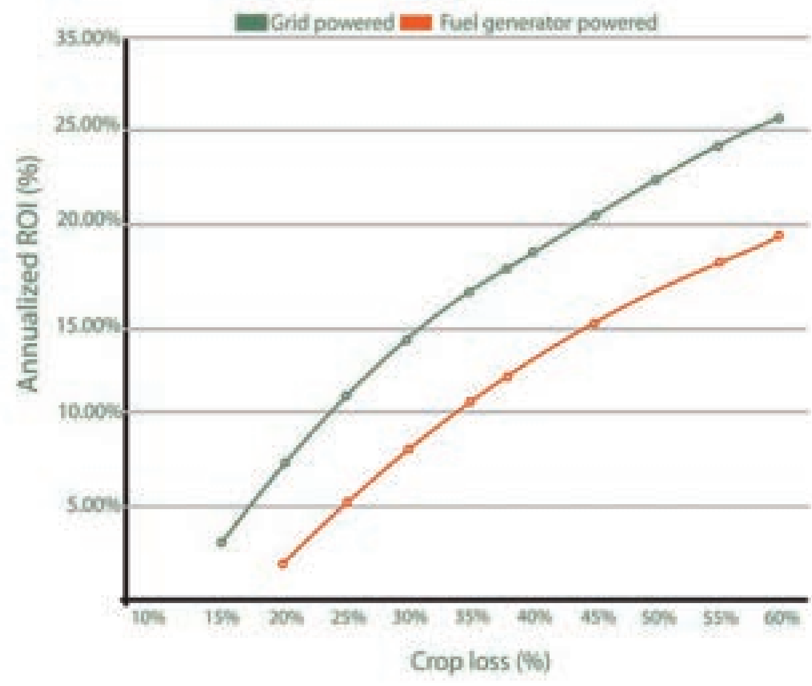

Based on the following assumptions:

Vineyard Installation costs/7 years

	Hectares		Acres	
Vineyard Size	12		30	
Length of Emitters	60,000 Meters		65,614 Yards	
Initial Cost	Grid	Generator	Grid	Generator
per Meter	$5.61	5.19	5.13	4.75
Total CAPEX 7 years	$336,600	$311,400	$336,600	$311,400
Seven Year Averages				
Average annual Crop Loss	5%	7.5%	10%	
	Average Yield Tons/ha - 9.88		Average Yield Tons/Acre - 4.0	
Base Crop Revenue per ton	$1,500	$2,500	$5,000	$8,000
Annual Revenue Recovery in $				
5.0 % Annual Loss	8,892	14,820	29,640	47,424
7.5 % Annual Loss	17,784	29,640	59,280	94,848
10 % Annual Loss	26,676	44,460	88,920	142,272
Grid Powered				
ROI at 5% in 7/yr	5.41 yr	3.24 yr	1.62 yr	1.01 yr
ROI at 7.5 % in 7/yr	5.00 yr	2.00 yr	1.00 yr	0.63 yr
ROI at 10 % in 7/yr	2.50 yr	1.50 yr	0.75 yr	0.47 yr
Generator Powered				
ROI at 5% in 7/yr	5.00 yr	3.00yr	1.50 yr	0.94 yr
ROI at 7.5 % in 7/yr	5.00 yr	2.00 yr	1.00 yr	0.63 yr
ROI at 10 % in 7/yr	2.50 yr	1.50 yr	0.75 yr	0.47 yr

FIGURE 5 An ROI calculation is determined by the historic frequency of frost/freeze events and their severity over multiple years, coupled with the added benefit of a Frolight system that can provide protection down to 21.2° F. Many vineyard owners have chosen to install their first system on their most severely affected vineyard site to test the value of the Frolight equipment.