SHuR FARMS®
Frost Protection
Division of Recovery P.T. Inc.

1890 N. 8th Street, Colton, CA 92324
877-842-9688, 909-825-2035
909-825-2611 FAX
info@shurfarms.com
www.shurfarms.com

Dry Farming Frost Protection

Frost protection without water is not only possible, it may even be preferable in some areas. In order to understand the options available it is necessary to understand some basic concepts and methods. Radiation frost develops in an organized, specific way and steps can be taken to lessen the detrimental effects by recognizing and relieving or eliminating 'frost pockets'.

Understanding that frost can only occur in areas of cold air accumulation, being able to recognize these areas, and dealing with the dynamics of katabic air flows will substantially reduce the severity and instances of frost damage. The following handbook will outline the ways of optimizing the growing area to be as naturally frost free as possible. Naturally frost free is the best that a grower can get. The optimization process may be the most powerful and beneficial method of frost protection.

Not all areas can be made completely naturally frost free, but it is important to remove all detriments to natural frost avoidance and to not create problems. We will explore the following *areas;*

1. *How frost develops- A discussion of where the cold air that causes frost damage comes from and why.*
.
2. *Recognizing accumulation areas and adapt planting layout and varieties for maximum frost resistance.*

3. *Understanding active and passive frost protection methods.*

4. *Methods to evaluate and analyze the growing area.*

5. *Optimizing the growing area.*

Part 1

How Frost Develops

When the sun goes down at night during a typical radiation frost condition (clear skies and no wind), the ground will usually be warmer than the air because during the day the ground is absorbing and storing heat that is coming from the sun. When the sun goes down the earth will start losing heat through long wave radiation. Differing materials radiate heat at different rates and the faster a material radiates its' heat, the more quickly it cools. For example steel will radiate heat faster than wood, and the ground will radiate heat faster than the air. Dry (low relative humidity) air will lose heat faster than humid moist air. Also, different densities of soil will lose heat at different rates, for instance, loose sandy soil will cool more quickly than heavy dense clay soils and dry soil will cool faster than wet soil.

Due to the soil losing heat more rapidly than the air due to **radiation*** losses, and because the soil is warmer than the air at sundown, then at some point during a frost night the soil temperature and the air temperature will become the same. Because the soil continues to lose heat more rapidly than the air, as the night progresses the soil will become colder than the surrounding air temperature. It is not until the soil becomes cooler than the air that there is a risk of radiation frost occurring. As long as the soil temperature remains warmer than the air, then there can be no cooling of the atmosphere along the ground and thus there is no possibility of radiation frost.

When the soil becomes colder than the air layer in contact with the ground, the ground will start chilling the air from the ground up through **conduction**.** This is when the inversion layer starts to develop as now the lower layers of the atmosphere are colder than the higher ones. The most dangerous nights for frost is when the ground has very little heat stored in it due to cold winds or cloud cover during the preceding days inhibiting the absorption of energy and heat into the soil. If the skies clear during the night and the ground is at or near the air temperature, then the ground will quickly become colder than the air and the inversion will start quickly. Under these conditions, the risk of frost is greatly increased. The longer the period of **unobstructed radiation losses*****, the more cold air will be generated that can accumulate in areas of insufficient drainage causing increased temperature differentials within the vineyard, and a greater risk that frost damage can eventually occur.

As the lower air layers of the atmosphere are chilled along the ground, the molecules become heavier and denser than the warmer layers above and the air is now 'stratified'. The denser and heavier strati closer to the ground are affected by gravity and will flow downhill if there is a slope. This downhill flow, called 'katabatic flow', is along the ground and the depth of the flow will vary from a few inches to several feet depending on the amount of cold air being generated upstream and the angle of slope. The area upslope of the basin that is feeding cold air (the air-shed) into it determines the amount or mass of cold air, while the angle of slope determines the speed of the air moving downhill. The steeper the slope, the faster the downhill speed and the lower to the ground the coldest air will flow. If critical temperature cold air does not submerge plant tissue, then there is no risk of frost damage. This is why steep hillsides and other well drained areas do not experience radiation frost damage, even though the ground temperature may be the same as the ground temps in the accumulation areas.

Under inversion conditions, the air is a stratified fluid, subject to the laws of fluid dynamics and behaving like all fluids do. Unlike some fluids that become more viscous (thicker and lower flow ability) as they become colder (like motor oil and molasses), air becomes less viscous as it becomes colder and so can flow even more easily. Any area where more cold air flows into than what can naturally flow out is considered to have 'insufficient drainage' and will start to accumulate cold air. When this cold air mass builds to a height that submerges plant tissue, there is risk of frost damage. These areas are the typical 'frost pockets'.

Even as the regional climate is sufficient to grow the crop, the air that is chilled from the ground is colder. As long as there is sufficient drainage to allow this colder air to remove itself, or the plant tissue is at a height above the critical cold air layers, there will be no frost damage. As this colder air flows downhill and accumulates in the lower valleys and frost pockets where there is insufficient drainage**,** or as the flow deepens, it may submerge the plant tissue in a lethal cold air mass. There are seven identified ways that cold air can accumulate, which will be discussed in a future article.

Because the ground loses energy (heat) at a consistent rate during unobstructed radiation events regardless of the time of year, and the hours available for radiation loses are fairly consistent during the growing season, the amount of cold air generated and the damage patterns during a frost night are also fairly consistent. A working number is 100K BTU's lost every hour/acre of ground (the actual BTU losses will vary due to soil type, density and moisture content of the ground), and it doesn't matter if this is a January night or a July night. The difference is that in July there is much more heat stored in the ground and a much shorter night. The ground may not have the time to lose enough heat to cool below the air temperature, thus there would be no cooling of the air along the ground, no stratification, no katabatic flow, no accumulation of cold air, and no inversion developing.

The longer the period of unobstructed radiation losses, the deeper the cold air mass can become in the accumulation areas and the greater the temperature 'differential' will be between the well-drained areas and the accumulation areas. For instance, if the regional temperature is 33F, then hillsides and other well drained-areas will be at or very near this temperature. Because the mass of cold air is determined by the heat loss from the air shed areas feeding into the accumulation basin, and the speed of flow is determined by the angle of slope, there is a specific amount of time required for cold air to accumulate and start differentiating from the regional temperature. For instance, it may take 2 hours for enough cold air to flow into a specific frost pocket to build up deep enough to submerge plant tissue in lethal cold air. Every hour may lower the temperature in the frost pocket by 1F, so after 2 hours the temperature on the hillside is 33F and in the pocket it will be 31F. If a wind or clouds come up every hour, the accumulated cold air and temperature differential will be removed and there will be no threat of frost damage. However, if there is no wind or clouds for 5 hours, then the temperature on the hillside will still be 33F (regional low temperature), but the temperature in the frost pocket will now be 28F.

* ***Radiation*** *is how energy travels through space. Energy lost from the ground due to radiation will not warm the air, but will instead be lost to outer space if the size of the radiation waves will fit through the 'atmospheric window' of 8 -14 microns. This size of radiation wave is called infrared or long wave radiation.*

**** ***Conduction*** *is a process of heat transfer from molecule to molecule. An ice cube on one end of a steel rod will cause the rod to conduct heat all the way from the other end of that rod, eventually cooling the entire rod.*

*****___Unobstructed radiation losses___ *is when there is no break up of radiation loses such as clouds moving in overhead or a wind that destroys the stratification. For example, if it takes 4 hours for a valley basin to fill with cold air under unobstructed radiation conditions, and wind or clouds come every 2 hours, the basin will not fill and there will be no frost. If, however there is no obstruction to the filling for 6 hours, cold air will build to a level that will submerge plant tissue in a lethal cold air mass creating the potential for frost damage.*

Part 2

Recognizing accumulation areas and optimizing planting layout and varieties

Types of accumulation

Cold Air River:

A cold air river is a concentrated streamline of cold air that is created when cold air flows into a gulley or swale from the surrounding higher areas. The cold air continues downhill due to gravity. This is a dynamic (moving) mass of cold air that is contained within swale boundaries and the mass of cold air can get wider and deeper as it flows downhill. The increase in the mass of cold air downstream is due to the addition of cold air that enters the gully from the surrounding area. There will be a difference in temperature between the air inside of the swale and the air outside. The air inside the swale can be several degrees colder because the coldest and heaviest molecules will flow into the gully, displacing the warmer air layers. Frost damage that 'snakes' its way through an orchard is an indication of a concentrated streamline of cold air.

Cold Air Flooding:

Flooding occurs when cold air builds up below the growing area and then overflows back into the growing area. Flooding occurs when the growing area itself has sufficient drainage capability, but the area below has insufficient drainage and accumulates cold air. In most instances the basin below will not overflow its normal capacity during every frost event as most basin areas do have some natural drainage. Where there is some drainage then buildup will occur only when the frost event is severe enough to produce more cold air flowing into the lower basin than the natural drainage can expel. When the buildup of cold air exceeds the holding capacity of the basin, cold air will overflow the basin and flood into the vineyard.

Cold Air Lake:

Cold air lakes exist where there is a static mass of air that builds up or pools in a specific area due to an obstruction to air flow or a low pocket. As cold air enters a basin and builds up, the warmer air in the basin is displaced upwards.

In the case of ‘damming’ or an obstruction, cold air can build up to several times the height of the obstruction and back into the orchard. The lower the slope angle of approach to the obstruction, the deeper cold air can build up in relation to the height of the barrier before finally flowing over.

Converging Air Currents:

Converging air currents are created when two or more streamlines of cold air come together at or near opposing angles, and at the point of a sharp bend in a swale or drainage. The collision of the air streams causes chaotic and backwards (eddy) currents that work against and obstruct the normal flow causing a build up of cold air.

Flat Area Accumulation:

Flat area accumulation is the result of the build up of cold air solely from the area directly underneath the growing area.

In a flat area there is no slope and so there is no movement of cold air. The main driver of the cold air buildup is heat loss from the ground. The ground loses heat through long wave radiation, cools, and then cools the atmosphere from the ground up. Where there is no air movement due to low or no slope and no differences in the soil that would cause differing heat loss rates, cold air will build up evenly along the ground causing a damage pattern that affects the lower levels of the crop first and most severely. The higher up the tree, the less affected it is.

In flat area accumulation there is no direct outside influence of cold air from surrounding higher areas. Some large flat basins that are surrounded by hills can have an overall temperature loss throughout the region. The distance of the surrounding hills and mountains from the growing area is a factor in whether or not the cold air generated on the hillsides will affect the growing area.

Another factor is the length of the frost event. When frost conditions start early in the evening and are not interrupted by wind or clouds, the cold air generated from surrounding hills will be able to travel further. If there is incursion of cold air from outside the growing area that combines with the cold air generated within the growing area, the chance for frost damage increases.

There may be temperature differences in areas of flat topography due to the soil conditions. Sand, loose soil and dry soil will lose heat faster than heavier or wet soil and dark soil will absorb more heat during the day than light soil. During the night, these soils will cool more rapidly, and cool the atmosphere directly above them more rapidly. Because there is no movement of air and thus no mixing, then the air temperature above the sandy areas will be colder.

Other variations in temperatures over a flat area can be attributed to shading from vegetation, differences in soil moisture content, ground cover variation and soil condition such as disked or hard packed.

Plain slope:

Accumulation of cold air on a plain slope is caused by the steady deepening of the cold air mass due to the consistent addition of cold air to the slope. Cold air generated inside the orchard combines with cold air generated uphill and outside the orchard. The downhill speed of the cold air mass on the slope is governed mainly by the slope angle, surface conditions, and temperature of the air along the ground. When the inflow of cold air exceeds the capacity of the slope to drain itself, cold air will build up and may submerge plant tissues in lethal cold air.

Lessening Slope

Lessening slope accumulation occurs where cold air that is flowing downhill slows because the slope angle gets less. Since the amount of cold air that is flowing downhill is determined by heat loss from the ground in the air shed area above, and the speed of the mass traveling downhill is determined by the angle of slope, when the slope gets less the cold air mass will slow down. This will cause the cold air mass to build up at the point of the lessening slope and submerge plant tissue in lethal cold air.

Planting layout and varietal considerations

While accumulation areas have the potential to be colder than areas with sufficient drainage, this does not mean that there will be frost damage, only that that these accumulation areas will be colder than the well drained ones under radiation conditions. Planting varieties that are known to be more frost resistant or varieties that bud out later in the season will greatly reduce the potential for frost damage.

Orient the rows to facilitate cold air drainage down the slopes if possible and remove any obstructions like berms, cover crops, structures, brush, etc. that will impede drainage on the slopes. Enhance and create obstructions that will impede cold air entrance into the growing area. No opportunity to restrict cold air entrance and enhance cold air drainage should be overlooked, no matter how small.

Analyze and determine where the cold air is coming from and where it is draining to before modifying obstructions so as not to remove anything beneficial.

Part 3- Understanding active and passive frost protection methods

Within the categories of Passive and Active frost protection measures, there are three main sub- categories of frost protection – those methods that *protect against the cold air* by putting on a shield, those that focus on *preventing the area from getting cold* by warming the air, and those that focus on *making the plant less susceptible to the cold.*

Methods that *protect against the cold air* include over tree irrigation, trunk wraps, anti-frost insulation and foams. These methods are not reliant on an inversion layer and may have some effect under advection conditions. However, if advection freeze is a significant problem then the grower should be looking at planting crops or varieties more suitable to the region.

The second category focuses on *preventing the area from getting cold.* In this category there is wind mixing (wind machines and helicopters), heaters, under tree irrigation and cold air removal technology (Shur Farms Cold air Drain®). Passive measures that focus on keeping the area warmer include air barriers and diversions, soil management and cover crop management. These methods work by reducing the time that the crop is in a super cooled state or exposed to critical cold temperatures. Limiting exposure to lethal temperatures reduces the likelihood and statistical risk of actually having frost damage. When using methods such as wind machines and helicopters that produce an aggravating effect that can promote ice crystallization, it is critical to start the protection early before the plants are in a super cooled state.

The third category of frost protection focuses on *making the plants less susceptible to frost damage.* This is accomplished by making the plant more healthy and therefore more frost hardy, delaying bud break, and by retarding the formation of ice crystals. In this category there are copper sprays, nitrogen and chemical monitoring, and soil enhancements. Passive measures include late pruning, optimization of varieties and site selection.

Frost Protection Tools – Active measures

Overhead Sprinklers – (In use since 1940's. Many systems installed in the early 60's.) Over tree irrigation is a common and effective method of frost control when used properly. The disadvantages of over tree irrigation are numerous and over tree irrigation can be a dangerous method that has the potential of causing serious damage when used incorrectly.

Prior to deciding on the use of over tree irrigation, the issues associated with proper use and causes for failure of the system should be considered and resolved.

Over tree irrigation cannot be used for winter frost conditions, it is suitable only for spring and fall frosts as the temperatures during winter will cause the water lines and emitters to freeze.

Advantages

-Does not depend on inversion layer to be effective.
-Effective.
-Quiet.

Disadvantages

-High maintenance.
-Requires large amounts of water (50-80 gallons per minute/acre). The protection gained is directly proportionate to the amount of water applied to the canopy.
-Water should be applied uniformly per acre and not cycled.
-Can cause heavy ice load on plants.
-Must be started early due to a dip in the air temperature at start-up caused by evaporation.
-Can cause diseases from saturated soils, and the leaching of nutrients & other chemicals.
- Will cause more damage to the crop in the event of a system failure than if no frost protection was used.
-Overhead sprinklers for frost control cannot be used with wind machines.
- Overhead sprinklers should not be used in any area that is wind prone, as wind and water will cause evaporation making the area colder than if no protection was used at all.

How they work

Water emitted from the sprinkler heads encapsulates the crop by freezing around it. As more water falls on the encapsulating ice, the freezing of that water releases heat into the ice and keeps it just under 32 deg. F. This is cold enough to stay frozen and yet warm enough to coat the crop and act as a barrier from the surrounding colder air. This is what protects the crop from damage. Water that does not freeze on the crop because the spray pattern misses the target will either freeze in the air or fall to the ground where it will soak in or freeze on the ground surface. If the water freezes in the air or the ground surface, some heat will be released into the air but this is not a significant factor in the way that over tree irrigation protects crops. Since the protection is mainly derived from water freezing on the ice, the temperature of the water pumped through the system is not a factor unless it is too cold to travel to the sprinkler heads and freezes in the lines.

If constant application of sufficient water is not maintained, the temperature of the ice covering the plant tissues could fall to well below the surrounding air temperature. The ice that is covering the crops must remain wet on the outside with a steady drip of water off the ice. This will insure that there is a constant freezing of water going on and there is enough water freezing to release a sufficient amount of heat to keep the ice shield at a safe temperature. As more ice freezes on the crop and the ice shield grows larger, a larger volume of water is required to release enough heat to keep the larger mass of ice at a safe temperature. As long as water is dripping from the ice then there is enough water. If the mass of the ice builds up too large for the amount of water being applied, or the water supply is shut down, the ice will dry up and start to evaporate. This will cause the temperature of the ice to fall well below the temperature of the surrounding air and cause more severe damage than if there had been no frost protection at all.

When using micro sprinklers or pulsators, care must be given to the potential low temperatures in the protected area. A 15 gpm/acre micro sprinkler system operating at less than 27 deg. F is at risk of failure. The higher the volume of water in an over tree irrigation system, the lower the temperature that the system will protect against. The actual safe temperature is dependent not only on water volume but also the line sizes and types, emitter droplet size, and distance of water travel. Each system should be evaluated for the safe working temperature and compared with the actual known low temperatures in the area. For example, if there is a history of temperatures in the protected area going below 27 degrees F, a system with 15 gpm/acre or less is not suitable.

The less water volume in a system, the greater the risk of the water suddenly stopping due to its low temperature threshold. This will happen due to;

1. The lateral water lines freezing because there is not enough water mass and/or speed and turbulence through the lines to avoid freezing,
2. The emitter heads freeze at sufficient low temperature and clog the emitters shutting down water spray, and
3. Water that is emitted from the sprinkler heads freezes in the air before it reaches the ice on the crop because the mass of each droplet is too small. If the water freezes in the air, the heat is lost into the atmosphere and provides no benefit.

Over tree water must not be turned off until all the ice has melted and the sun has come up. If it is turned off earlier than this, there can be ice evaporation and damage.

The most critical point is the start up of an over tree irrigation system. During start up, the water spray will evaporate until the relative humidity of the surrounding air reaches 100%. In order for water to evaporate it must use heat from the air to vaporize. This causes the air temperature to drop substantially. This effect is known as ‘evaporative dip’, and every over tree irrigation system must contend with this. The procedure is to consult a chart that is supplied by the sprinkler manufacturer to determine the temperature dip at a specific relative humidity. The lower the relative humidity, the more evaporation will take place and the lower the temperature will drop. The sprinkler system must be turned on prior to the critical point where the current temperature minus the evaporative dip equals lethal temperature. If this point is missed, then the sprinkler system cannot be turned on. If it is, the crop may be damaged by the temperature dip. The crop will then be covered in ice as if everything was working fine, but in the morning after the ice melts, there are substantial losses due to cold damage that might not have occurred if the sprinkler system was left off.

Of course the standard problems of pump failure, or simply running out of water affects any type of irrigation system.

Most effective applications

Systems that use more than 50 GPM/Acre. Even micro sprinklers and pulsators should never be used with less than 30 gpm/acre as the risk of failure is too high.
When used to overcome very small regional temperature deficits (advection freezes).
When used in conjunction with cold air drainage (Shur Farms cold air drain).

Least effective applications

Systems that are under 30 gpm/acre for micros or under 50gpm/acre for full solid sets.
Wind prone hillsides and flat areas.
When used in conjunction with conventional wind machines.
Winter frost conditions and large regional temperature deficits.

Under tree Sprinklers and flood irrigation

Advantages

-Effective.
-Less risky than over tree sprinklers.
-Less water required than over tree sprinklers (25-45 gallons per minute per acre should be applied.)
-Lower application rates have the advantage of reducing water logging soils & leaching of nutrients & other chemicals.
-Good retention of energy.
-Quiet.

Disadvantages

-Requires inversion layer to be effective.
-Effectiveness depends on the amount of water converted to ice.
-Overall effect is small & confined to the area under the canopy.
-Misters and micro sprinklers work for under tree frost protection only if application rates and coverage are adequate. Small droplets or 'foggy' mist do not compensate for a low volume of water, however fog is an effective protection method in its own right.

How they work

Water emitted from the sprinkler heads or flooded along the ground freezes either in the air or on the ground. When the water changes state from a liquid to a solid (water to ice) 'latent heat of fusion' releases heat stored in the water. The surrounding air molecules are warmed by this release of heat and will rise due to thermal buoyancy to the point that they are the same temperature as the air around them. They will then 'stack' and begin to cool. Even after the warmed molecules are positioned at the point of stacking, they continue to cool and then descend back to the earth where they will be re-heated in the same manner and rise again. This process of continual up and down motion is convection and it is the same process that takes place with heaters. An artificial thermal ceiling is created and only the air molecules below that ceiling are heated and reheated to maintain a higher than natural temperature below the ceiling.

Unlike fuel heaters, the stacking point of the heated molecules when using under tree irrigation is never higher than the canopy of the crop. With fuel heaters the ceiling can be much higher. The temperature increase that can be attained is the temperature at the stacking height of the heated molecules, which is dependent on the volume of water applied and the conversion rate of the water to ice. Water that is emitted in too large of droplets may not freeze completely and soak into the ground. Water that soaks into the ground loses much of its frost protection ability, so when choosing emitters, droplet size and spray pattern consideration must be given to the expected low temperatures and soil conditions. When using flood irrigation, it is desirable to have the water slightly turbulent. Turbulence will increase the surface area that is exposed to freezing cold air and promote ice formation. It is ideal when there is a mixture of ice and water, or slush, on the ground with either flood irrigation or under tree sprinklers.

Even though under tree irrigation is associated with some evaporative cooling as with over tree irrigation, there is no danger to the crop because the colder air is already lower than the fruiting zone and cold air does not rise.

Failure of an under tree irrigation system due to loss of water will have no additional negative effects other than losing your frost protection. It is considered a 'safe' system.

Most effective applications

Under tree irrigation is useful in nearly all applications as long as the water is not applied to the fruiting surface.
Under tree irrigation should be applied as uniformly as possible throughout the protected area.
When used with cold air drainage (Shur Farms Cold air Drain)

Fig 8 – Portable wind machine

Wind Machines

(First used in the 1920's in California, but not generally accepted until the 1940's-1950.

Wind machines have gone through a long evolutionary process with a wide range in configuration and styles.

Advantages

-Most beneficial in flat topography.
-Enhances the effects of heaters.
-Can work with under tree irrigation.
-Generally, the maximum gain in temperature is 45% of the difference between the temperature at the base of the wind machine and the center of the wind machine blade.
-Maximum benefit encompasses approx. 8% of the total coverage area.

Disadvantages

-Requires inversion layer to be effective.
-If the inversion layer is too high, stirring up the air with a rapidly rotating propeller is not going to bring warm air down to freezing fruit and can make the area colder.
-The effect varies throughout the protected area.
- Wind agitation can disrupt the plants ability to super cool.
-Noisy.
-Cannot be run in windy or advection conditions.

How they work

Wind machines are wind mixers. Their main function is to push air from the warmer, higher stratus downward to mix with the colder air along the ground. A secondary effect is to push the cold air layer close to the ground out of the area or slightly upwards to mix. Most wind machines rotate 360deg. to cover a circular area.

Wind mixing does not assimilate cold air molecules into warm air molecules. There is little or no transfer of heat from one molecule to another. For a transfer of heat to take place there must be sufficient contact time between the warm molecules that are forced downward and the cold molecules along the ground. Due to the forces of thermal buoyancy, the warm molecules have a strong tendency to separate and rise back to their natural position above the cold molecules. The continual rotation of a wind machine results in an end to the forced convection in a given spot and therefore, the maximum effect in any one area is temporary. When the warm air is blown down, there are warm molecules and cold molecules 'mixed' together. When the propeller moves and the wind stops blowing, then the warmer molecules will rise to their natural positions over the cold molecules until the propeller returns and re-mixes the air. This causes a continual rise and fall of temperatures throughout the protected area as the machine rotates.

The temperature increase due to wind mixing can be expressed as the 'sustained' temperature increase or the temperature 'flux'. Sustained increase is the average and flux is the temporary maximum rise in temperature. Because wind machines have a varying effect over the protected area, the sustained temperature increase should be used to determine the effectiveness of a system throughout the protected area and not the high temperature flux.

The maximum temperature increase that can be achieved with a wind machine is relative to the difference in temperature between the ground and the center of the wind machine blade. Depending on the distance from the wind machine, this difference is between 0% and 45%. It is therefore critical to locate wind machines in relation to the damage area with their effect, and also to avoid locating them in low pocket areas that accumulate cold air. Because wind machines are not designed to remove cold air accumulation, and cold air is continually added to accumulation areas throughout the night, cold air will build up around the wind machine and lessen the difference in temperature between the ground and the center of the wind machine blade rendering the wind machine less effective.

In fig 9, the distribution of warm air around the wind machine and the effects at given distances from the machine are shown. This chart assumes a flat area with no drift. In most instances the circumference is slightly more eccentric shaped. On slopes, the distance of the air throw is reduced on the uphill side and elongated on the downhill side. There is a circular band area that represents approximately 8% of the protected area that will have the greatest sustained and flux temperature increases.

It is also important that the wind machine blade be as high as possible to reach the warmest air available. Current technology limits this height to about 40 – 45 ft from the ground as the ability to propel warm air molecules to the ground from greater heights is not feasible. When locating a wind machine on hill, the distance to the protected area must be considered.

The greater the difference in temperature between the warm air molecules forced downward and the cold air molecules along the ground, the greater the force of thermal buoyancy. This results in more power being required to propel the warm air downward and less time warm and cold molecules will be mixed before separating and rising upward. This will result in higher temperature increase flux in relation to the sustained temperature increase.

In fig 10 the average temperature increase is charted. With a 10 deg. F temperature difference between the ground and the middle of the wind machine blade, the average temperature increase over 10 acres is 1 deg. F, but smaller areas have substantially higher average increases.

When placing a wind machine the best effect should be aligned with the damage area and care must taken to avoid a build up of cold air around the perimeter. Besides mixing warm air with cold air, a wind machine will push cold air around the perimeter of it area of influence. The cold air can accumulate there and submerge crops. The effect is a circle of damage around the perimeter of the protected area. Overlapping the affected circumference with other wind machines is one way to avoid the circle of damage that happens when a wind machine pushes cold air out of the area and it builds up around the edge of its area of influence.

Wind machines blowing uphill can obstruct cold air drainage resulting in accumulation and damage on the hill that would not have occurred otherwise. Another consideration is to avoid blowing cold air from one area to another or into a neighboring orchard. Position wind machines to blow cold air into a safe area.

<u>Most effective applications</u>

Flat areas and large open plain slopes.

<u>Least effective applications</u>

Frost pockets, gulleys and swales, cold air lakes.
Complex undulating topography.
Advection conditions and regional temperature deficits.
Crops less than 12” from the ground.
When used in conjunction with over tree irrigation.

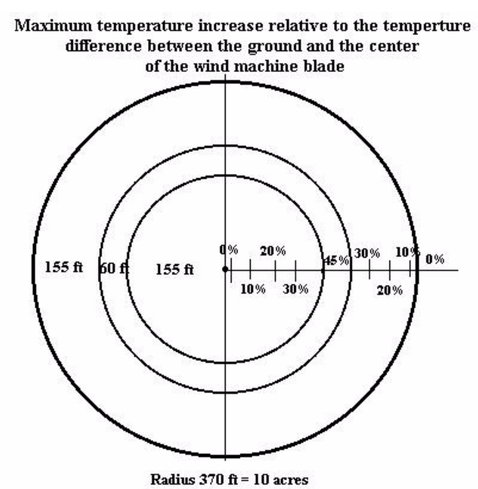

Fig 9 – Temperature flux chart

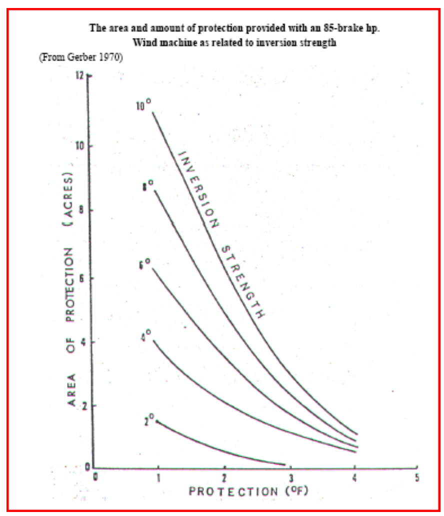

Fig. 10 – Average temperature increase chart

<u>Shur Farms Cold Air Drain®</u>
(Has been in use since 1990’s)

Cold air removal technology is designed to eliminate micro climates by removing or preventing cold air accumulation.

Fig. 11 – Shur Farms Cold Air Drain®

Advantages

-Works in accumulation areas (severe & chronic frosty valleys, pockets, & swale areas).
- -Can be used to control bud break
-Alters individual microclimates.
-Results are easily verifiable.
-More economical to run than wind machines or sprinklers.
-Environmentally friendly.
-Quiet.
-Removable at end of season.
-Low maintenance
-Uses passive measures (airflow dams & diversions) to maximize effectiveness
-Enhances the effects of over tree sprinklers, under tree irrigation, wind machines, and heaters.

Disadvantages

-Requires inversion layer to be effective.
-Cover crops must be maintained low to the ground to improve air flow.
-Obstructions to air flow must be removed

How they work

The Shur Farms Cold Air Drain® lessens the temperature difference between the cold, frosty areas that accumulate cold air, and the areas that are naturally frost free. This is accomplished by removing the cold air that accumulates due to the lack of sufficient cold air drainage capacity. Under natural conditions, hillsides and other areas that are well drained do not experience frost damage because lethal cold air does not build up deep enough to submerge the crops. The coldest and heaviest air molecules along the ground are constantly drained off due to the gravitational pull causing katabatic air flow. As the coldest air is drained off, the warmer air layer from above becomes relatively the coldest and heaviest and drops down. As this layer is drained, then the next layer drops down and drains off. As long as the capacity of an area to drain off cold air exceeds the amount of cold air entering into the area, then there is sufficient drainage. An area that has sufficient drainage is termed naturally frost free, because of the inability of cold air to accumulate. With the exception of advection frost or a region wide temperature deficit where the entire region is submerged in lethal cold air, frost damage only occurs in areas where there is cold air accumulation. Even when there is a regional temperature deficit that is radiation in nature, the accumulation areas will suffer greater damage than the well drained areas.

The Shur Farms Cold Air Drain® removes accumulated cold air through a hydraulic process of selective extraction that mimics the natural process of cold air drainage.

The Shur Farms Cold Air Drain® extracts the coldest and densest molecules closest to the ground and forcibly drains them upwards out of the protected area. By removing the coldest air from along the ground, the warmer air layer above will move downward as it becomes relatively the coldest and heaviest layer. As this layer is drained, the next layer drops down.

The process used to move the cold air into the cold air drain is called ‘Selective extraction of fluids of differing densities’. This is the same process that is used in removing water that accumulates in the fuel tank of an airplane and removing cream from milk.

In the airplane, fuel is lighter and less dense than water and so water in the fuel will separate and settle to the bottom of the tank. Opening the drain valve on the bottom of the tank will allow the water to flow down and out. Even though the fuel tank is the length of the wing, the water molecules along the bottom of the tank will flow horizontally for as long as necessary to reach the drain and flow out. After all of the water is drained out, the fuel becomes relatively the heaviest layer and moves downward. Since all of the water must be removed before any fuel can come out the drain, the pilot knows that when one drop of fuel comes out of the drain, all of the water is gone.

Instead of draining downward, the Shur Farms Cold Air Drain® forces the cold air upward through a specially designed wind tunnel. Depending on the application and whether the need is to capture a moving mass of cold air and direct it into the wind tunnel or to remove a static mass of cold air from a frost pocket, different designs of the Cold Air Drain® are used. All of the designs are used for the same basic purpose; the coldest air from along the ground is pulled into the bottom of the machine and ejected upwards. As the cold air is ejected upward it crosses through the warmer air layers. As the cold air molecules pass through warmer air, mixing of cold and warm molecules begins. This is termed 'ascendant mixing' because the mixing is caused when the ascending jet stream of colder air crosses the warmer air layers. Warm air is drawn into the jet stream and mixed with the cold air. Transfer of heat from the warmer air molecules into the colder air molecules warms the jet stream, lessening its density and making the molecules lighter.

When the jet stream reaches its dissipation height from the ground, approximately 300ft, the temperature and density of the air molecules in the jet stream is approximately the same as the surrounding temperature. At this point the air disperses horizontally into the upper inversion. The cold air that is removed from the ground has changed density and temperature through the assimilation of warm air into the jet stream. It is permanently removed and cannot fall back down to earth.

Cold air removal can be used to drain accumulation areas or to prevent cold air from entering into an area and thus avoid accumulation altogether. There are seven major ways that cold air can accumulate which will be discussed in a later chapter. Draining cold air cannot cause additional damage under any circumstances, although it is effective in preventing frost only under radiation conditions. Only under radiation conditions does atmospheric stratification exist. Under advection conditions, the machine would revert to non-selective extraction and remove air from the area immediately surrounding the machine. Since under advection conditions the air is the same temperature throughout the zone, there is no detriment to this effect, and since advection conditions can quickly turn into radiation frost with the clearing of the skies (and back to advection), it is beneficial to leave the cold air drain running. It is considered a safe method.

Cold Air Drain® in Conjunction with Other Active Frost Protection

Cold air drainage is compatible with all other forms of frost protection. The effect is to lower the ceiling thereby enhancing their effects by simulating a stronger inversion. Most methods of frost protection rely on an inversion to be effective and the stronger the inversion, the greater the effect. Care should be taken to create a 'sink' area around the Cold Air Drain® machine of 20ft around the perimeter where the air is undisturbed. To create a sink area, the Cold Air Drain® should be located at least 325 ft from a wind machine and 20ft from any sprinklers or heaters. This allows the cold air to settle and reach maximum stratification prior to entering the machine.

Most effective applications

Cold air pockets, swales and gulleys, lessening slopes, converging air currents, slopes and other areas of cold air accumulation.
In conjunction with a perimeter barrier to avoid cold air entrance along an uphill side.

Least effective applications

Regional climate deficits and advection frost conditions.
Crops less than 12" from the ground.
Row crops where the rows are perpendicular to the slope.

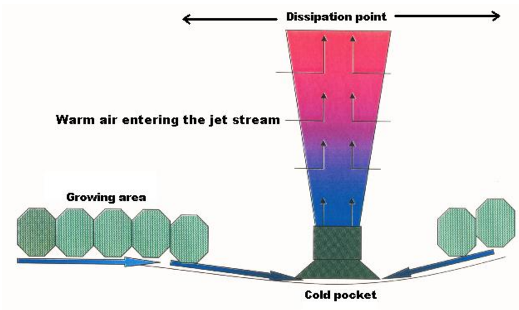

Fig. 12- Cold air drain in a static air mass

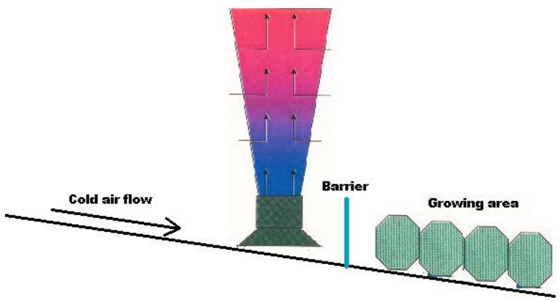

Fig 13 – Cold air drain in a dynamic flow

Heaters

Fig 14 – return stack heater

(Fossil fueled heater technology was developed in the early 1900's-1920's.)

Advantages

-Heaters throw off some heat.
-Work best when used with wind machines and in accumulation areas or static air mass.

Disadvantages

-Expensive to operate. (Oil requires 30-40 heaters/acre. Propane requires approx.70 heaters/acre. A heater usually burns between .5 and 1.2 gallons of fuel per hour.)
-Labor intensive
-Air pollution and environmental issues may be problematic.
-Between 75-85% of heat from conventional oil or propane heaters can be lost through radiation into the sky.

How they work

Heaters warm the surrounding air. The heated air becomes lighter and less dense than the surrounding colder air causing it to rise. The heated air begins to cool as it ascends and at some point above the ground, it is the same temperature and density as the surrounding air. The greater the difference in temperature between the heated air and the surrounding cold air, the faster and higher the heated air will rise. 'Thermal buoyancy' is the term used to describe the phenomenon of warm air rising, and the greater the difference in temperature between the cold air and warm air, the more ‘buoyant’ the warm air becomes.

When the heated air rises to the point where it is the same temperature as the surrounding air, it becomes ‘neutrally buoyant’ and will stop rising. At this point the thermal boundary line that is created is known as the ‘ceiling’. Since a molecule of a specific temperature, for example 30deg. F will not push away another molecule of the same temperature and density, heated molecules of the same temperature will begin to ‘stack’ under each other. As more air is heated, it will eventually stack under the ceiling until the temperature in the entire area is equalized.

As the heated air molecules begin to cool, they become less buoyant and start to descend back towards the ground. Other heated molecules take their place. The cooling molecules will fall until they are close enough to the heat source to be re-heated and rise again. This process is called ‘convection’. Only the molecules that are stacked below the ceiling are heated thus avoiding the total loss of heat into the atmosphere.

The best heaters operated correctly are 75% -85% inefficient. This means that 75-85% of the fuel burned to create heat is lost to the atmosphere, doing no work and providing no benefit. In reality no other process of any kind in any industry would tolerate such inefficiency.

The ceiling height can be controlled by modifying the amount of heat or heat concentration coming from the heat source. A more indirect heat – or radiant heat – will impart the same amount of heat energy (BTU’s) over a larger area, while turning the heaters down and burning less fuel will provide less BTU’s. Either approach will provide less temperature difference between the heated molecules and the natural molecules resulting in less thermal buoyancy. This will result in a lower ceiling or ‘stacking’ height. In most cases the ideal ceiling height is just slightly above the canopy.
Using more heaters, each with less fuel consumption will have the same effect as fewer heaters that are more radiant.

When a molecule is super heated with a direct non-radiant heat source such as a bonfire, then the heated molecule will rise to much higher level before it stacks and may never have the chance to convect back down into the protected area before the damage is done or the sun comes up. In these cases, the grower will only have succeeded in heating the atmosphere above the orchard, making no impact on the temperature inside the orchard.

The proper method for using heaters is to start with a low heat volume in order to build a ‘ceiling’ and to quickly complete the convection process. No real protection takes place until this convection process is complete. When the temperature below the ceiling is equalized, the heat can be slowly turned up in order to raise the ceiling height.

The limit of the temperature rise inside an orchard is the temperature at the ceiling. For instance, if the temperature at 15ft above the ground is 3 deg. F higher than at the ground, and this is where the ceiling is set, then the maximum rise in temperature inside the orchard will be 3 deg. F. In order to achieve a higher temperature rise, then the ceiling must be raised which would require significantly more fuel in relation to the temperature increase.

Since the thermal gradient (the temperature rise at a given height increment) spreads out as the height from the ground increases (for instance there may be a 3 deg F. rise from the ground to 15ft, but the next 15 ft may only rise 1.5 deg. F, and the next 15ft after that may rise only 1/2 deg F), fuel consumption rises exponentially to the rise in temperature in the protected area. Due to time constraints, there is a maximum height that the ceiling can be established at in order to complete the convection process before damage occurs to the crop. The earlier the heaters are started, the higher the ceiling can be. The limit to the temperature increase with heaters in a protected area is determined by the strength of the inversion and the cost of fuel that the grower is willing to endure.

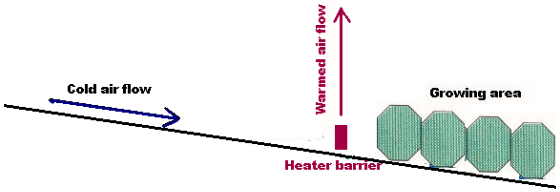

Fig. 14 – perimeter heater barrier.

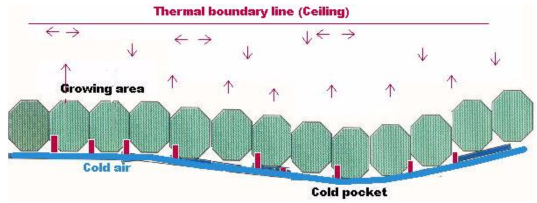

Fig 15- Heater convection currents

Most effective applications

Heaters work best in accumulation areas and areas with a non-moving (static) mass of air such as flat ground, cold pockets, and cold air lakes.

Least effective applications

Areas with dynamic air flow such as hillsides and swales. In these areas, the heat released into the atmosphere is quickly replaced be fresh cold air entering the area. This is the same as trying to heat a river; all of the water that is heated is quickly replaced by fresh cold water.

Uphill Perimeter boundaries – Heaters that are positioned at a close distance to each other along an uphill perimeter boundary to create a thermal barrier will not provide heated air into the protected area downhill. The heat from the heaters will not flow downward into the orchard – heat only goes up, never down. The effect is to heat the cold air moving downhill from outside the orchard (due to katabatic flow). When the cold air molecules come in contact with the heater barrier, the cold air that would normally flow into the orchard will be heated and rise thus blocking its entrance into the orchard. Since it is the cold air generated outside and upstream of the orchard that causes most or all of the damage inside the orchard, the avoidance of cold air entrance does offer substantial protection against frost damage, however creating a barrier with heaters is inefficient and only marginally effective. Due to large gaps of heat close to the ground between the heaters cold air can 'leak' through the barrier and the high cost of this method makes it by far the least efficient way to block cold air from entering an orchard.

Heaters in conjunction with wind machines

When wind machines and heaters are used together they work in a completely different way than when either wind machines or heaters are used separately. Wind machines and heaters together is essentially forced air heating. It is possible to achieve a high temperature increase because the wind machines will capture and recirculate more of the heat produced by the heaters through forced convection than is achieved through natural convection. Wind from the wind machines act as the ceiling and forced convection is faster acting than natural convection.

When using wind machines and heaters during an advection freeze, the wind machines will blow colder air down to mix with the heat produced by the heaters. Under advection conditions, it is essential that the heaters be positioned to provide complete coverage of the area and that there is sufficient heat applied to overcome the temperature loss due to blowing colder air downward.

Fog Systems

Advantages

-Effective
- Low water usage

-Low danger of soil saturation
-Quiet

Disadvantages

-Drift of fog is difficult to contain.
-Fog systems in the US are rare due to the liability issue of fog drifting onto highways and causing accidents.

How they work

There are two major ways that fog works to prevent frost. First, the ground loses heat through long wave radiation. These radiation waves are approximately 10-15 microns in diameter. Natural fog particles are the same size as these radiation waves, and so the fog will absorb and reflect the heat lost from the ground preventing it from escaping into the atmosphere. This will keep the ground warmer, slowing the cooling of the lower layer of the atmosphere.

The second effect is that fog will eliminate atmospheric stratification and the associated temperature differences within the fog zone, equalizing the temperature throughout the fog zone eliminating any micro climates.

Since fog is affected by gravity, it will flow in the same manner as cold air along the ground. It will find the coldest spots and get into hard to reach places. Because fog is affected by gravity, it is difficult to maintain a deep layer. Fog tends to compress and become denser when more is added instead of maintaining its density and building up a deeper layer. For this reason, the best use for fog is to retard heat loss from the ground.

Artificial fog that is indistinguishable from natural fog can be made by forcing water through an orifice at extremely high pressures to achieve the correct particle size. A well distributed fog bank will have about the same effect as an under tree irrigation system with less than 10% of the water usage.

Most effective applications

Frost pockets, static accumulation areas and flat areas.

Least effective applications

Windy areas.

Helicopters

Advantages

- Helicopters are a form of wind machine
- No water usage

Disadvantages

- Expensive
- Dangerous
- Can cause severe damage if called too late
- Unreliable due to too many variables

How they work

Helicopters are a form of wind machine. They push warm air from above to mix with the colder air along the ground, same as a conventional wind machine. Sometimes the grower will install temperature sensitive lights throughout the protected area that will go on when the temperature falls to a critical level. The helicopter pilot will fly from light to light to 'put them out' by raising the temperature.

One helicopter is normally used to protect between 25-50 acres. The capacity of a single helicopter is dependent on the weight and size. The heavier they are, the more power can be applied and the more air that is pushed down.

<u>Most effective applications</u>

Flat areas and large open plain slopes.

<u>Least effective applications</u>

Overall, helicopters are not reliable and way too expensive to be considered a primary source of frost protection. Delays in arrival, pilot skill, helicopter types, weights and styles, and other variables prevent helicopters from being an effective method of frost protection.

Chemical Sprays

<u>Advantages</u>

- Inexpensive
- Easily applied

<u>Disadvantages</u>

- Most studies show that chemical sprays of zinc & copper show no measurable benefits.
- Sprays to eliminate ice nucleating bacteria are ineffective because of the natural abundance of ice nucleators already in the bark & stems, and the apparent ability of ice to nucleate around dead bacteria.

<u>How they work</u>

Copper based sprays are designed to reduce the numbers of ice nucleating bacteria. Copper is a bacteria stat, which means that it will inhibit the introduction of new bacteria and as the old ones die off, the population decreases. The theory is that after several days from application, there will be lower numbers of ice nucleating bacteria and less risk of ice crystallization in the plant cells. Because of the lower risk of ice crystallization, the plants should be able to super cool to lower levels.

New technology of introducing competing bacteria to lessen the presence of ice nucleating bacteria has shown some promise, but is not currently available due to issues related to genetic engineering.[1]

[1] **The use of genetically engineered bacteria to control frost on strawberries and potatoes. Whatever happened to all of that research?**
R.M. Skirvin, E. Kohler, H. Steiner, D. Ayers, A Laughnan, M.A Norton, M. Warmund Univ. of Illinois, Dept of Natural Resources and Enviornmental sciences, Univ. of Missouri, Dept of Horticulture

Other types of sprays such as polymers and elastics are designed to seal the plant tissues to avoid transpiration of water, keeping the plant from ‘freeze drying’. By keeping the plant hydrated, it is assumed that the plant will be able to super cool to lower temperatures before ice crystallization begins.

Most effective applications

Neither copper based nor polymer sprays have shown a consistent ability to enhance the natural super cooling of the plants.[2] Copper sprays are effective in controlling some fungus and bacteria that can cause damage to the plant. This makes for a healthier plant and a healthier plant is more frost resistant than a sicker one.

Burning Debris

Advantages

- Releases some heat

Disadvantages

- Environmentally disastrous.
- These fires provide little radiant heat, and smoke does not provide any frost protection.

How they work

Burning debris is a form of heater.

Most effective applications

Setting up and burning many small fires.

Least effective applications

Burning large, hot fires with lots of smoke.

Frost Protection Tools – Passive Measures

Passive frost protection methods are those that require no outside energy such as burning fuel or electricity. Passive measures work by helping to create a natural environment that promotes health and optimum growing conditions for the crop.

Site and varieties selection

Advantages

- Can be integrated into existing management practices at little or no cost.

[2]**Spring Frost Control** North Carolina Winegrape Growers Guide, NC State Univ. cited Sugar et al, 2003

- Environmentally sustainable practice.
- Optimizes variety suitability within a growing area.

Disadvantages

- Data logger study may be required to determine the temperature correlation between microclimates in a growing area.
- A study may have high costs.
- Should be done prior to planting.

How it works

Site selection is the most effective and efficient method of any frost protection. Choosing a site that avoids frost conditions by being naturally well drained, and matching the crop to the regional climate, soil and other conditions will ultimately have the best return on investment of any frost protection method.

The larger the growing area, the more likely it is that there will be areas that accumulate cold air. In rolling hills and undulated topography there will always be areas that experience cold air accumulation as the higher spots drain themselves. The drained cold air will eventually either be obstructed or enter into an area faster than it can drain out. Areas that are at risk for cold air accumulation are sometimes not planted wasting valuable growing area.

Barriers and Diversions

Advantages

- No fuel required and does not need to be turned on or off.
- Effective when used properly.
- Environmentally sustainable practice.

Disadvantages

-The proper design and placement of barriers and diversions is essential.
- Barriers and diversions have the potential to cause serious damage if not used properly.
- May have high installation and acquisition costs.

How they work

Barriers block or divert cold air that moves along the ground.

The use of barriers to accomplish manipulation (either as a barrier or diversion) of cold air currents is the most effective and powerful passive frost protection method after site selection. The existence of heavy vegetation at the low end of a vineyard or orchard can result in the obstruction of cold air drainage and may be the cause of severe frost damage. A similar obstruction along the high side perimeter can block cold air entrance into the vineyard and result in an improved situation for the downstream vineyard, but have an equal negative effect on another area where the cold air backs up or is diverted to. Barriers can be used to create dams and obstructions to air flow as well as diversions that will deflect the cold air flow out of the protected area and into a safer location. Barriers have the potential to create a substantial impact, but barriers alone do not remove the cold air so that leaves the question of where is the cold air going? Barriers are most effective when used in conjunction with cold air drainage.

Air flow obstruction or diversion can be accomplished by natural or artificial methods, such as heavy vegetation, soil berms or non permeable artificial barriers. Buildings and road embankments also serve as barriers, and heaters can create a thermal barrier blocking the entrance of cold air flows. Wind machines blowing uphill can create a barrier to cold air flowing off the hill.

The existence of a barrier at the low end of an orchard can result in the obstruction of cold air drainage, causing cold air accumulation resulting in severe frost damage, but in another similar circumstance where there is cold air buildup from below, the same barrier might act to block the entrance of cold air into the orchard.

The existence of a barrier at the high side of an orchard can block cold air entrance into the orchard. By creating an obstruction to the air flow and slowing the incursion of cold air into the orchard there will be an improved situation for the downstream orchard. If there is an orchard upstream of the barrier, and since a barrier does not remove cold air, there will be an equal negative effect of cold air buildup to crops being grown above the barrier as a result of cold air accumulation. Eventually, cold air will breach the barrier, flowing over the top, and finding gaps and other openings. Cold air will build to a height above the barrier that is determined by the height of the barrier, angle of approach and the viscosity of the air. When the buildup reaches its maximum containment height, air that flows over the top will mix with warmer air aloft and continue to move downhill.

An obstruction built to intercept cold air flows at an angle in an effort to deflect and divert the cold air flows to a safe area must consider the viscosity and low momentum of katabatic air flows. Mostly, cold air flows see these types of diversions as barriers and will tend to build up behind and around them. Diversion barriers must be designed with the proper height and angle of interception to keep air flows moving.

Barriers of any sort should never be used or modified without the benefit of an air flow model and analysis of the effects of such a barrier or diversion. Barriers have the potential to create a substantial impact both positive and negative.

Barriers alone do not remove cold air so that leaves the question: Where is the cold air going to go?

Most effective applications

Upstream the orchard to block out cold air flows from above.
When used in conjunction with cold air drainage.
Diverting lateral cold air incursion

Least effective applications

When used without cold air drainage.
Improper placement

Soil management

Advantages

- Can be integrated into existing management practices at little or no cost.
- Environmentally sustainable practice.
- Can raise night time temperatures 1 – 2 deg. F

Disadvantages

- None

How they work

Cultivation- Loose soil will lose heat during a radiation frost event faster than dense, packed soil. Disking loosens the soil and provides more surface area to transfer heat out of the soil. While disked soil also absorbs more heat during the day for the same reason, the additional heat absorbed is quickly lost after the sun goes down.

Water application- Darker soils will absorb more heat than light colored soils and soil that is moist along the top 12” of the surface will retain more heat than dry soils during a radiation frost event. Applying water to the soil surface during the day will darken the soil and allow for more heat to be absorbed. Keeping the top 10”-12” of the soil surface moist at night will retard heat loss and keep the soil warmer.

Soils should be mowed and left hard packed instead of disked or tilled during the frost season and kept moist to a depth of 10” -12” to help retard heat loss from the ground during the night. Since it is the ground that gets cold and cools the air that causes frost damage, slowing the cooling of the soil surface will slow the cooling of the air.

Most effective applications

All areas.

Least effective applications

None.

Cover Crop management

Advantages

- Can be integrated into existing management practices at little or no cost.
- Environmentally sustainable practice.
- Can raise night time temperatures in some cases up to 4 deg. F

Disadvantages

- May impact soil nutrients and natural pest and weed control.

How they work

During the frost season cover crops should be kept to a minimum in areas that are prone to frost. The recommended maximum height is less than 3” from the ground. During the day, a thick cover crop will prevent sunlight from hitting the ground. This will retard heat absorption into the ground making the ground colder at sundown. An area with thick cover crop can be 1-2 deg. F colder during the night than the same area with the cover crop removed.

On a slope, cover crop will obstruct cold air drainage, creating an accumulation of cold air on the slope and causing frost damage. A slope with 12” high cover crop can be as much as 4 deg. F colder at 48” from the ground than the same slope with cover crop kept to less than 2 ½” high. On slopes, cover crop is never an option during frost season and must be kept to a minimum.

There are two ways that cover crop can be beneficial for frost protection. The first is with some under tree irrigation systems. Water from the sprinklers will be trapped in the cover crop, preventing it from soaking into the ground and allowing it to freeze releasing heat into the protected area. If the cover crop is on flat ground in an area that is shielded from the sun by a thick canopy or other obstruction then there is no detriment, otherwise the loss of heat into the ground from the sun far outweighs the benefit of additional water that will freeze.

The second is that under rare circumstances, usually after several days of cloud cover, the soil will retain more heat with a thick cover crop during the day. This happens when the daytime conditions, cold and cloudy, are such that the soil does not absorb heat but instead gets colder. The cover crop acts as a blanket. In all other instances, cover crop is not beneficial for frost protection. Water is best managed by optimizing the spray pattern and droplet size, and the advantages under the second circumstance are minimal.

Most effective applications (for removing the cover crop)

Remove cover crop in sun bathed areas and on any slope.

Least effective applications

Cover crop management will have the least importance in flat areas under a heavy canopy and other sun obstructed areas.

Late Pruning, chemical and other dormancy extending methods

Advantages

- Can be integrated into existing management practices at little or no cost.
- Environmentally sustainable practice.
- Slows bud break and extends dormancy

Disadvantages

- May impact harvest dates

How it works

Late pruning, chemicals and other methods that can delay bud break will keep the plant dormant until later in the season when the risk of frost decreases. Even a few days of extended dormancy can significantly decrease the risk of frost. Check with your orchardist or viticulturist to see which methods may be suitable to your specific varieties.

Part 4 - Analyzing and evaluating the growing area

To understand the potential frost risks in a growing area, begin by collecting relevant information including frost history, orchard specifics (acreage, age, skirt/cordon height, etc.) and the frost history of blocks of similar crop and varieties in the surrounding area. If reliable information is available from nearby growers and orchards and then compared to the subject area, the comparisons can give a feel for the risk and probable intensity of frost damage, even when there is little actual information from the protected area itself.

Obtaining topographic and air flow models from appropriate sources like Shur Farms Frost Protection will help not only in identifying where cold air is entering, exiting and accumulating in the growing area, but also to determine similar micro climates in the surrounding orchards that can be used for comparison.

A comparison of the micro climates within the growing area is made by installing data loggers in strategic spots that the air flow models have determined may have a potential for cold air accumulation and installing data loggers in similar areas of known frost damage history in the local surrounding area. A comparison of temperatures between these areas under radiation conditions will give an accurate view of the potential for frost damage in that particular area and for the same crop and varieties. For instance if a data logger records 32f on a given night in an area that is known to have been frost free for 10 years, and another logger records 33f at the same time in an unplanted area, then the assumption can be made that if the same crop and variety is planted there, frost risk is less than once every 10 years.

Comparisons must be made within the same regional climate as there is no correlation of micro climates that exist in different regional climates. Data must be compiled during radiation events, but not necessarily on nights where the temperatures fall below critical levels. The most beneficial data is from the long uninterrupted nights of clear skies and no wind. The longer there is unobstructed radiation losses, the greater the temperature differentials that will develop and the more relevant the information is. Several months of data may need to be considered in order to get a relevant and useable sample. The comparison uses the data collected to create a “virtual“ frost damage history. A virtual damage history can be compiled for any area, even if it is newly graded or the outside factors contributing to the micro climate inside the protected area have recently changed. If the outside factors change after the data is collected, such as a tree line removed or a structure is built, the acquired data may no longer be relevant and should be re-evaluated at that time.

Part 5 - Optimizing the growing area

Any subsequently designed frost protection system will start by optimizing the growing area with passive measures that naturally enhance cold air drainage and block or retard cold air intrusion. The optimization will reduce the actual temperature differentials within the growing area. Optimization methods include barriers, soil management, row orientation and crop height. Active frost protections can then forcibly remove or mitigate the effects of any remaining cold air accumulation in the growing area.