FROST MITIGATION

HANDBOOK

V 001.01 - NOVEMBER 2015

NETAFIM™
GROW MORE WITH LESS

NOTE

All the drawings in this document are for the purpose of illustration only. The actual product details and infrastructure condition may differ in any actual application.

FOREIGN LANGUAGES

In the event that you are reading this manual in a language other than the English language, you acknowledge and agree that the English language version shall prevail in case of inconsistency or contradiction in interpretation or translation.

CONTENTS

USE OF SYMBOLS

The symbols used in this manual refer to the following:

WARNING
The following text contains instructions aimed at preventing bodily injury or direct damage to the crops, the frost mitigation system and/or the infrastructure.

CAUTION
The following text contains instructions aimed at preventing unwanted system operation, installation or conditions that. Failure to follow these instructions might void the warranty.

ATTENTION
The following text contains instructions aimed at enhancing the efficiency of usage of the instructions in the manual.

NOTE
The following text contains instructions aimed at emphasizing certain aspects of the operation of the system or installation.

ELECTRICAL HAZARD
The following text contains instructions aimed at preventing bodily injury or direct damage to the frost mitigation system and/or the infrastructure in the presence of electricity.

SAFETY FOOTWEAR
The following text contains instructions aimed at preventing foot injury.

PROTECTIVE EQUIPMENT
The following text contains instructions aimed at preventing damage to health or bodily injury in the presence of fertilizers, acid or other chemicals.

EXAMPLE
The following text provides an example to clarify the operation of the settings, method of operation or installation.
The values used in the examples are hypothetical. Do not apply these values to your own situation.

INTRODUCTION

The aim of this document

Frost mitigation constitutes an integral component of the cultivation of deciduous and other plants in numerous regions throughout the world.

Irrigation is distinctly the most effective and economical method of frost mitigation.

This guide provides fundamental data and explanations regarding the selection, configuration and practice of frost mitigation by irrigation.

NOTE
We remind our clients of the utmost need to properly operate and program all the components of the frost mitigation system to function according to needs, taking into account the human factor and the level of knowledge required to make the right decisions.

Safety

All local safety regulations must be applied when installing, operating, maintaining and troubleshooting the Netafim™ frost mitigation system and its components.

WARNING
In an agricultural environment - always wear protective footwear.

WARNING
Only authorized electricians are permitted to perform electrical installations!
Electrical installations must comply with the local safety standards and regulations.

WARNING
When handling acids and chemicals, always use protective equipment, gloves and goggles.

CAUTION
When opening or closing any manual valve, always do so gradually, to prevent damage to the system by water hammer.

FROST - THE PHENOMENON

Frost is the deposit of water vapor contained in saturated air, frozen as a result of a drop in temperature on solid surfaces. When solid surfaces in contact with air are cooled below the freezing point of water, ice crystals are deposited on them. Many plants can be affected or even destroyed by frost.
Frost conditions can occur during spring, fall or winter.

Springtime frost is one of the weather events that causes the greatest damage in fruit trees.
Frost mitigation is indispensable in certain geographical areas to insure regular harvest in terms of timing/delay, quantity and quality.

Deciduous trees and wine vineyards are naturally resistant to winter frost. However, in the spring, when budding and flowering commence, they become vulnerable to frost when temperatures drop below zero. This, in turn, leads in the short term to poor quality and delays of both leaves and fruit on trees and vines.

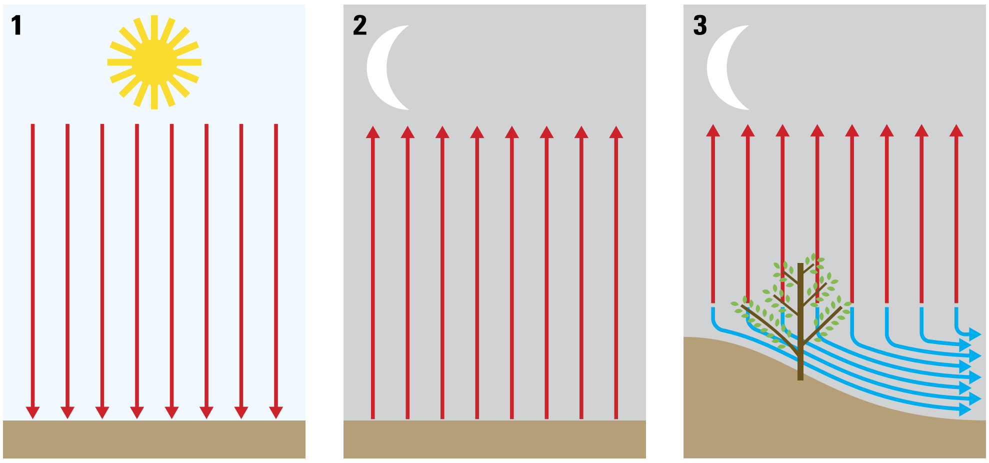
Other plants (such as avocado, citrus, potato, etc.) are susceptible to springtime frost in various growth stages. Frost events in these plants should be addressed in the same manner.

Types of frost

NOTE
Frost vs. Freeze: Although the terms frost and freeze are often interchanged, they describe two distinct phenomena. (See Radiation frost and Advection freeze below).

Radiation frost

1. In the daytime, solar energy warms the ground surface.
2. In the nighttime, the heat irradiated from the ground is reflected to the atmosphere.
3. Radiation frost occurs when clear skies, low relative humidity (RH) and light winds allow an inversion to develop, and temperatures near the surface drop below freezing. (See Thermal inversion, page 9).



Conditions:

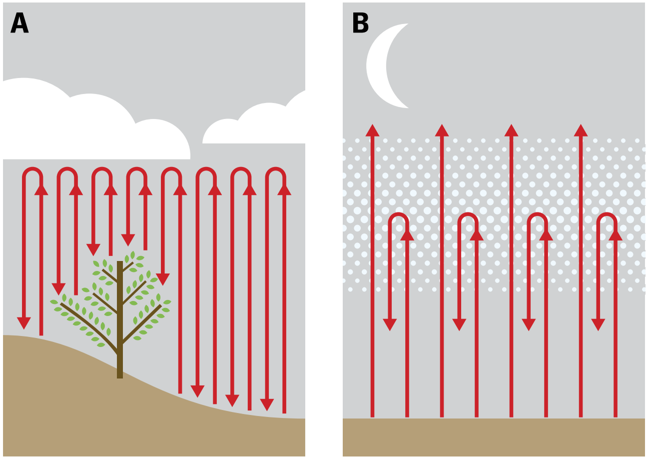
- Winds below 8 km/h (5 mph)
- Clear skies
- Temperature higher than 0°C (32°F) during the day

FROST - THE PHENOMENON

Radiation frost generally cannot be formed under conditions that prevent the development of an inversion

A. On cloudy nights, energy is reflected on clouds, and part of the heat returns to the ground level.

B. When the humidity is high, some of the heat is absorbed and some is reflected by the water vapor and the carbon dioxide (CO_2) in the air.

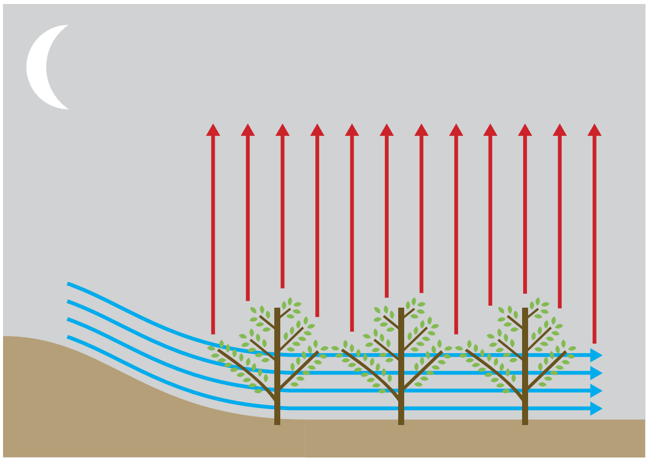


Advection freeze

An advective, or windborne freeze (also known as cold air drift) occurs when a cold air mass moves into an area, bringing freezing temperatures.

Conditions:

- Winds above 8 km/h (5 mph)
- Clouds may exist
- Temperature lower than 0°C (32°F) during the day
- Cold air mass 150 -1,500 m (500 to 5,000 ft) deep



NOTE
There are no effective means for protection against advection freeze,
Fortunately the phenomenon is infrequent.

Terms and concepts

Understanding the frost phenomenon involves the following terms and concepts:

Humidity

Humidity refers to the amount of water vapor present in the air.

There are several ways of expressing humidity, but the ones commonly used are relative humidity and dew point temperature.

Relative humidity (RH)

Relative humidity is the relationship between the amount of water vapor in the air and the amount of vapor necessary to saturate the air at the same temperature.

NOTE
Although commonly used, the relative humidity is not the best measure of humidity, because it depends on air temperature.
Warm air can hold more water vapor than cold air.
The amount of water vapor in the air will be lower at a lower temperature, even though the RH values are identical.

FROST - THE PHENOMENON

Dry Bulb, Wet Bulb and Dew Point Temperatures

The dry bulb, wet bulb and dew point temperatures are important to determine the state of humid air.

The knowledge of only two of these values is enough to determine the state.

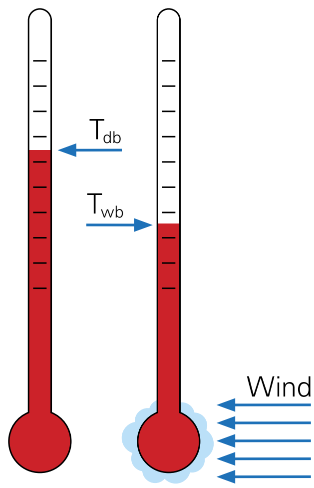
Dry Bulb Temperature - T_{db}

The dry bulb temperature, usually referred to as air temperature, is the air property that is most commonly used.

Dry bulb temperature refers basically to the ambient air temperature. It is called "dry bulb" because the air temperature is indicated by a thermometer and is not affected by the moisture of the air.

Dry bulb temperature can be measured using a normal thermometer freely exposed to the air but shielded from radiation and moisture.

Dry bulb vs. wet bulb temperature



Wet Bulb Temperature - T_{wb}

The wet bulb temperature is the temperature indicated by a moistened thermometer bulb exposed to the flow of air.

Wet bulb temperature can be measured using a thermometer with the bulb wrapped in wet muslin. The evaporation of water from the thermometer and the cooling effect is indicated by a "wet bulb temperature" lower than the "dry bulb temperature" in the air.

The rate of evaporation from the wet bandage on the bulb and the temperature difference between the dry bulb and wet bulb depend on the humidity of the air. The evaporation is reduced when the air contains more water vapor.

The wet bulb temperature is always lower than the dry bulb temperature except at 100% relative humidity , when they are identical (the air is at the saturation line).

Dew Point Temperature - T_{dp}

Dew point temperature is the temperature at which water vapor starts to condense from air (the temperature at which air becomes completely saturated). Above this temperature, the moisture remains in the air.

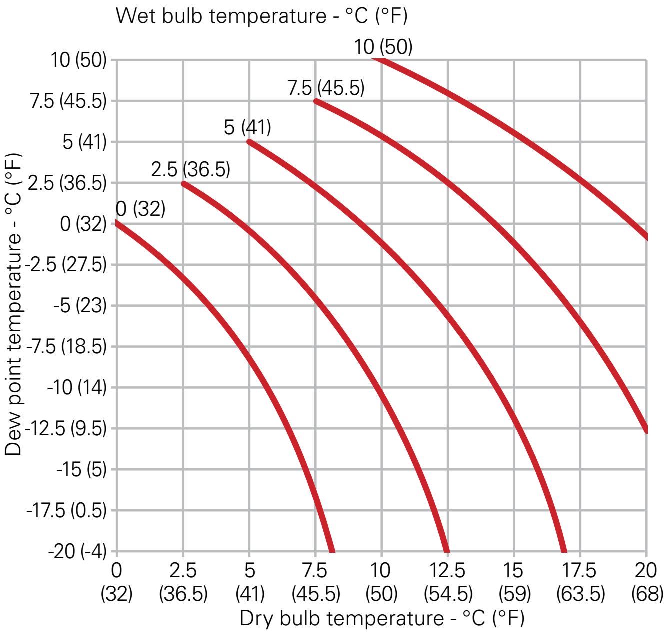
NOTE

- If the dew point temperature is close to the dry air temperature - the relative humidity is high.
- If the dew point is well below the dry air temperature - the relative humidity is low.

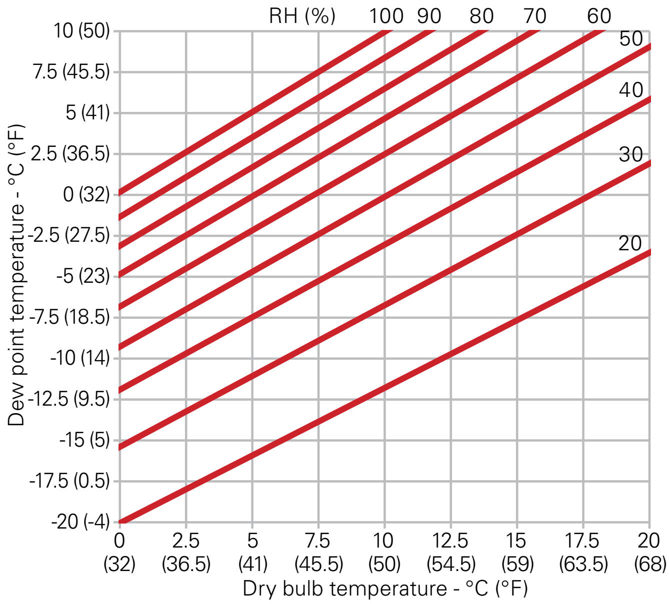
FROST - THE PHENOMENON

Dew Point Temperature Charts

Dew point temperatures
from dry and wet bulb temperatures



Dew point temperatures
from dry bulb temperature and relative humidity (RH)



Thermal inversion

On a clear night, the heat from solid objects (such as soil and plants) radiates out to space and surface temperatures drop significantly.

The temperature in the lower layer of atmosphere inverts, meaning that the temperature at the higher altitude (top layer) increases.

This is "inverse" to the normal daytime atmospheric conditions, or the "normal adiabatic temperature gradient", in which air temperature decreases with height.

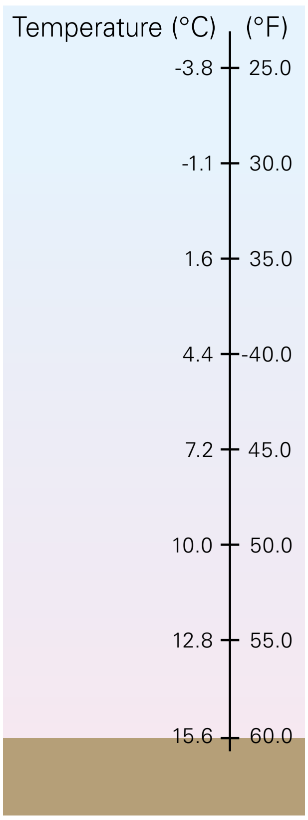
The thickness of the inversion layer varies from 10 to 60 meters (30 to 200 feet).

Two facts about cold air:

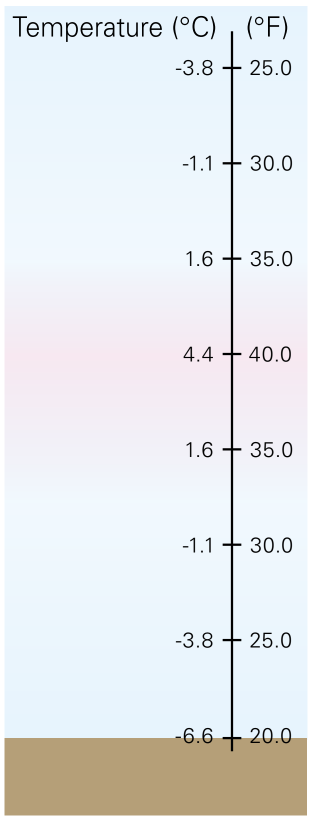
- Cold air is denser than warm air.
- Cold air forms near the ground in calm weather conditions.

Therefore, cold air accumulates at the ground level - this is known as surface temperature inversion.

Normal adiabatic temperature gradient



Inversion



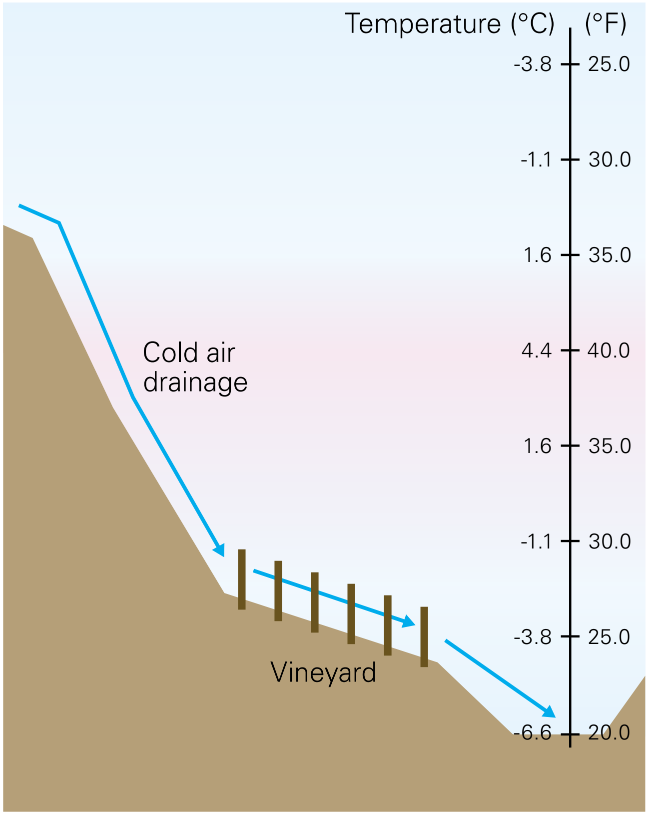
Microclimates

Growers in mountainous, hilly, or rolling terrain are familiar with frost pockets or cold spots. These are formed by cold air drainage, i.e., cold, dense air flows by gravity to the lowest areas of a field, where it accumulates. This causes temperatures to differ in relatively small areas; the climates of these areas are called microclimates. Frost can form in these areas even when the reported temperature is above the freezing point of water.

The effect of the topographic location of a vineyard on the air temperature stratification

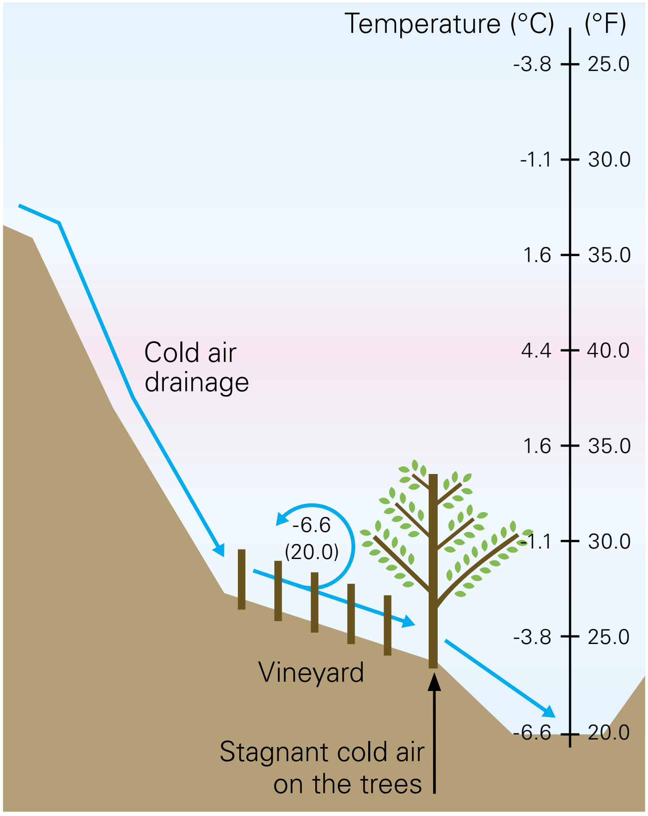
Thermal inversion

Cold air draining from higher ground passes through the vineyard, exposing it to a low temperature.



Thermal inversion with wind barrier

Cold air draining from higher ground is blocked by a line of trees at the edge of the vineyard, exposing it to an even lower temperature.



Microclimate monitoring

NOTE

The usual meteorological forecast is not sufficient for forecasting frost occurrences.

The topographical characteristics of the farm play a major role in the susceptibility of specific areas of the farm. These areas, usually at the lower parts or the farm, are typically subject to lower temperatures and thus more prone to frost than the farm as a whole. The term microclimate refers to the local climate confined in such an area.

The actual and forecast temperatures, cloud cover and wind speed can be observed and recorded. Although minimum temperatures may vary across a forecast zone due to microclimates, relative conditions for an area should be quite similar during each frost occurrence. It is extremely useful to record such data for each occurrence in selected parts of the farm.

FROST - THE PHENOMENON

In cloudy, breezy weather, the observed lows are likely to be very close to forecast values, but under clear, calm conditions, frost should be anticipated even when no frost is forecast.

The use of past observations can become an essential factor for predicting future conditions and modifying the zone forecast for a farm. The information collected will also allow the grower to place frost mitigation equipment in those areas where it will most likely be needed.

During a radiation frost, careful records of past occurrences can help make the critical decision of whether to begin implementing frost mitigation measures. This is especially critical in areas where overhead irrigation is used. Microclimate information gathered before the establishment of a crop can help the grower select the site, type and amount of frost mitigation equipment.

Critical temperature

Critical temperature is defined as the temperature at which plant tissues (cells) will be destroyed, ranging from below -18°C (-0.4°F) in the winter up to 0°C (32°F) in the spring.

The critical temperature is usually slightly lower than the freezing point of water. The point at which damage occurs depends on the actual duration of exposure of the plant to that temperature.

Many factors affect the critical temperature:

- Stage of growth - if the plant is in early stages of growth or is mature
- Fruit set - whether the crop is still on the plant or not
- Dormancy - whether the plant is actively growing or is dormant
- Plant water content - whether the plant is under water stress or not
- Overall plant health

Damage to crops

Many plants can be affected or even destroyed by frost. This varies according to the plant type, its stage of growth and the organic tissue exposed to low temperatures.

Damage caused by frost on crops results mainly from the extracellular (outside cell) ice formation inside the biological tissue of the plant, which extracts water from the cells, dehydrating them (FAO 2005).

EXAMPLE
Avocado damaged by spring frosts.

EXAMPLE
Apple - crop cycle
Critical temperature at each stage of growth

Stage		Destroyed	
		10%	90%
	Inactive		
	Silver tip	- 9°C (15.8°F)	- 16°C (3.2°F)
	Green tip	- 8°C (17.6°F)	- 12°C (10.4°F)
	½ green	- 5°C (23.0°F)	- 9°C (15.8°F)
	Firm cluster	- 3°C (26.6°F)	- 6°C (21.2°F)
	Pink	- 2.2°C (28.0°F)	- 4°C (24.8°F)
	Flower	- 2.2°C (28.0°F)	- 4°C (24.8°F)

For values of the critical temperature of different crops, consult FAO (the United Nations Food and Agriculture Organization) at http://www.fao.org

FROST MITIGATION METHODS

Introduction

All frost mitigation methods are based on preventing or replacing radiant heat loss. The proper choice of frost mitigation equipment for a particular site depends on many factors such as cost of the equipment, operational costs and additional labor requirements.

Comparing the most common frost mitigation methods

The following tables summarize the advantages and disadvantages of the different methods of frost mitigation.

Passive methods

Method	Advantages	Disadvantages	Comments
Site selection	• Best method of frost mitigation. • No operational cost.	• In many cases, the site is imposed and cannot be freely selected.	• Choose a location with good cold air drainage. • Visualize air flow and/or monitor minimum temperatures.
Crop selection	• No operational cost.	• The grower is not always free to select a crop or a variety.	• Select a crop or a variety known to be less sensitive to frost damage.

Active methods

Method	Advantages	Disadvantages	Comments
Heaters	• Relatively low installation costs. • Tolerates a certain delay. • Direct radiation to plants located around heaters.	• Between 75%-85% of heat is lost. • High energy consumption. • Fuel oil is expensive. • Less effective if no inversion exists. • Lighting of high heat makes them lose efficacy. • Contributes to greenhouse effect - use is forbidden in some parts of the world.	• Free-standing or pipeline.
Windmills	• Installation cost similar to heaters. • Works fairly well when used with other methods such as heaters or over -tree sprinkling.	• High energy consumption.	• Mixes warm air near the top of the inversion down to crop height.
Helicopter	• It may prove very effective as it can be adapted to the height of an inversion and moved to "cold points."	• Expensive to operate. • Helicopter availability. • Ineffective under little or no inversion.	• Blows warm air from near the top of the inversion down to crop height.
Irrigation	• Lower operational costs than heaters. • Same system can be used for conventional irrigation.	• Relatively high installation costs. • Risk of damage to crop if precipitation rate is inadequate. • Limbs may break. • Waterlog risk.	• Plant part protected by heat of fusion. • Irrigation must continue until complete melting. • Backup power source essential.

FROST MITIGATION METHODS

Comparing water with fuel

Water plays a very significant role in frost mitigation. Water is used in frost mitigation by taking advantage of its physical properties to add heat to the crop in order to protect the crop. Frost mitigation using water may be many times more energy-efficient than fuel-burning orchard heaters.

Main advantages of water:

- Lower operating expenses.
- Ease of operation.
- Suitable for multiple uses.
- Higher energy efficiency.

EXAMPLE

The following example demonstrates this using 3.785 liters (1 US gallons) of diesel fuel.

The fuel is burned in an orchard heater	The fuel is used to power a pump
The 3.785 liters (1 US gallon) of diesel fuel can be burned in an orchard heater system to produce heat and protect the crop.	As an alternative, the same fuel can be used to power a pump, providing water to the orchard via a sprinkler system.
The energy content of 3.785 liters (1 US gallon) of diesel fuel is approximately 140,000 BTU.	A pump using 3.785 liters (1 US gallon) of diesel fuel will pump 53,141 liters of water (234 US gallons).
So, if the fuel is burned, 140,000 BTU of heat are released into the orchard.	As 53,141 liters (234 US gallons) of water freeze, 16,848,000 BTU of heat are released.
140,000 BTU of heat	**16,848,000 BTU** of heat

16,848,000/140,000 = 120

As shown in this example,
using water for frost mitigation is 120 times more efficient than using fuel in orchard heaters.

Frost mitigation strategy

The proper strategy for frost mitigation must be chosen by the grower for each site. Once the decision has been made, several general suggestions apply to all systems.

For frost mitigation to be applied successfully, it must be handled with the same care and attention as spraying, fertilizing, pruning, and other cultivation practices. Success depends on proper use of the right equipment, sound judgment, attention to detail and commitment.

ATTENTION

Dos and Don'ts

- Complete preparation and testing of the system should be accomplished well before the frost season begins.
- Check the system shortly before an expected frost event.
- Be prepared. Problems that are handled easily during warm daylight can become monumental and even disastrous during a cold, frosty night when every second counts.
- Don’t delegate frost mitigation to someone with no direct interest in the result.
- Don’t shut down the system before the threat of frost has definitely passed.

FROST MITIGATION BY IRRIGATION

Introduction

For years farmers and researchers have acknowledged the value of water application to crops in periods when temperatures fall below the freezing temperature of water.

Irrigation has proven to be the most reliable and cost-effective method for mitigating frost.

Successful implementation of irrigation systems can mean the difference between complete loss of a crop and minimal damage.

Terms and concepts

Understanding frost mitigation by irrigation involves the following terms and concepts:

NOTE

The ability of water to evaporate at low temperatures
Water evaporates at any temperature, even at 0°C (32°F).

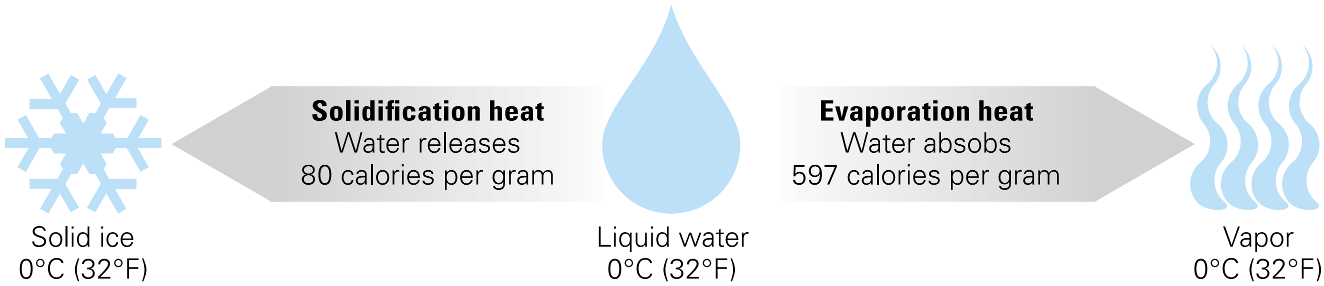
Evaporation is a different process to boiling:
Evaporation is an effect that happens at any time at any temperature.
Boiling is a bulk transformation that only happens at a certain temperature depending on the atmospheric pressure [100°C (212°F) at sea level].

When water evaporates, random movement of the water molecules at the surface allows some of them enough energy to escape from the surface into the air.

The rate at which water molecules leave a drop of water depends on a number of factors - for instance the temperature of both air and water, the humidity of the air and the size of the surface exposed.

Latent heat

Latent heat is the energy that water molecules absorb or release when changing state of matter.



Solidification heat:

The heat released when water freezes from liquid to solid ice.

When water freezes, it releases 80 calories/gram of frozen water.

During the time that liquid water is continuously applied to a plant, the heat generated when water freezes keeps the plant, in general, at 0°C (32°F), or very close to it.

Vaporization heat:

The heat required for water to change from liquid to vapor.

When water evaporates at 0°C (32° F), it absorbs about 597 calories/gram of evaporated water.

Anything that promotes evaporation, such as low humidity and wind, also facilitates general cooling.

FROST MITIGATION BY IRRIGATION

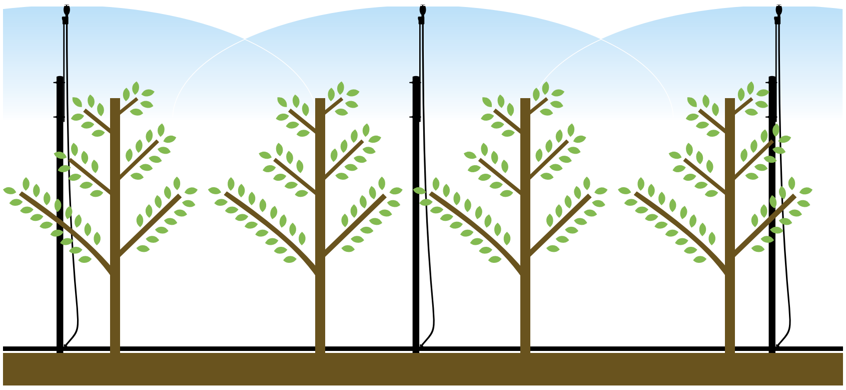
Frost mitigation schemes

Several methods of applying water to crops have been investigated, each using one or more ways of transferring heat energy to maintain temperatures above the plants' critical temperature.

Full-coverage over-crop sprinkling

Irrigation of the whole area during the frost event is intended to maintain the melting heat over the entire area.

- It protects buds and flowers with transparent ice.
- Continuous ice formation produces enough heat to maintain buds, flowers or fruits at safe, above-critical temperature.



NOTE

In frost prone areas, over-crop sprinkler irrigation is the most efficient and economical way to combat frost (Valérie Gallia, Irrigazette, March/April, 2001).

Properties

- Provides efficient frost mitigation at down to -5°C (23°F) at a 3 mm/h precipitation rate. Frost mitigation down to -8°C (17.6°F) can be obtained at an increased precipitation rate.
- Supplies adequate water supply in accordance with the freezing level and stage of growth of the crops.
- Distributes the water as evenly as possible over the entire area protected.
- Requires continuous irrigation during the period of protection.
- High uniformity is essential.
- A reliable sprinkler is required.
- Adequate water storage is needed.
- Special attention to cooling due to evaporation is required.
- Do not stop sprinkling too soon (See To water or not?, page 20).

Advantages

- Provides maximum protection.
- Covers sensitive parts of the plant.
- Intermittent operation allows a dramatic reduction in water consumption.

Disadvantages

- Critical opening and closing temperatures (See To water or not?, page 20).
- High water consumption.
- Risk of water-logging.
- Streams and impacts on roots.
- Degradation of soil structure by erosion or flooding.
- Washing off of decontamination substances and nutrients.
- May cause branches to break.

NOTE

Successful protection of the crops from the damages caused by frost by means of over-crop sprinkling depends on two crucial factors: **water application** and **uniformity**.

FROST MITIGATION BY IRRIGATION

Water application
Studies have shown that the relationship between the volume of water and the application area is one of the most important factors to consider when designing a system for frost mitigation.

The application flow is calculated after considering factors such as air temperature, wind speed and humidity levels.

Wind affects evaporation levels and uniformity of application. The influence of wind brings with it the need for a higher water application flow, to provide the same degree of frost mitigation as when there is no wind.

WARNING
If the application rate is inadequate, the damage caused may be **MORE SEVERE** than if frost mitigation measures were not applied.

WARNING
Ice transparency is very important!

Right
If irrigation is started on time, i.e., at the right temperature, the ice will be smooth and transparent.

Wrong
If irrigation is started too late, i.e., at too low a temperature, the ice will be milky and opaque, indicating cooling due to evaporation.

Uniformity
Effective frost mitigation also depends on the degree of uniformity with which the sprinkler distributes water.
- The sprinkler should be carefully selected.
- The spacing of sprinklers, application rate and operating pressures are important factors.
- Wind conditions should be carefully considered.

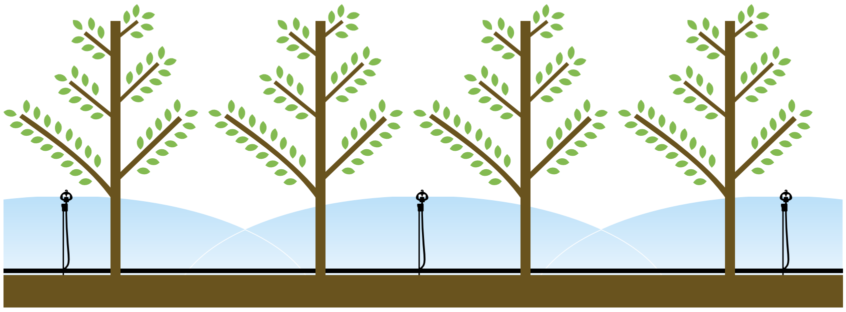
FROST MITIGATION BY IRRIGATION

Full-coverage under-tree sprinkling

Unlike over-crop sprinkling, under-tree sprinkling does not cover buds and flowers with transparent ice.

It creates ice on the soil under the tree canopies.

When water freezes, it releases energy that warms the air.

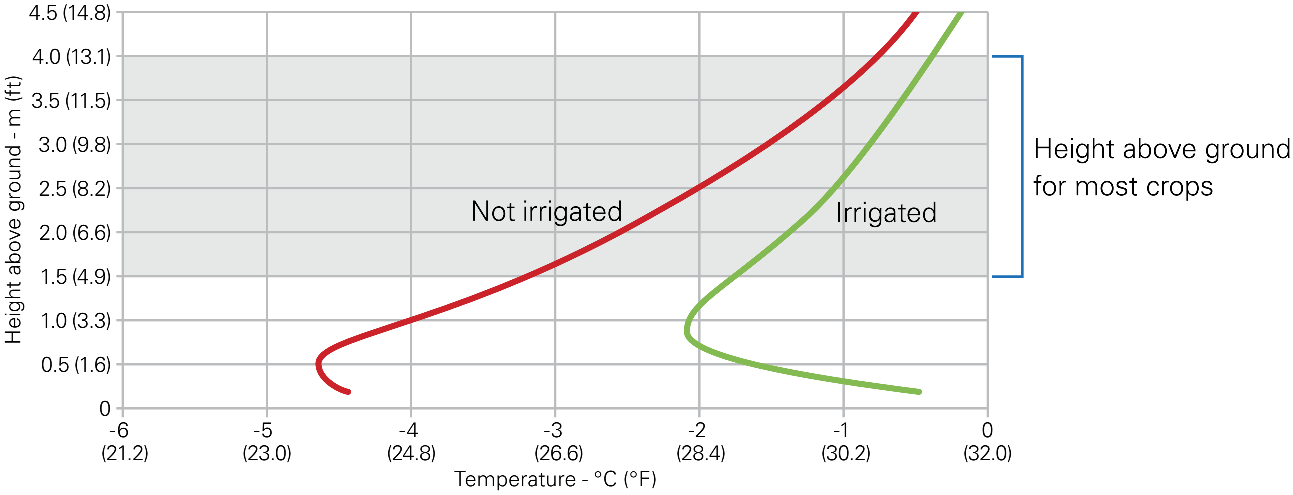


Properties

- Provides efficient frost mitigation down to -3°C (26.6°F) with a 3 mm/h precipitation rate.
- Needs an inversion layer.
- The level of frost mitigation is directly proportional to the amount and temperature of the water applied.
- Application depends on the height and type of crop.

EXAMPLE

Effect of under-tree irrigation



Advantages

- Dramatic reduction of water consumption.
- Lower costs (with automatization).
- Lower environmental impact.
- The larger the ice surface, the greater the protection.
- Operation in shifts or pulses (maximum 3 shifts, 2 minutes each).
- Low risk of error.
- The same system can be used for irrigation and frost mitigation.
- Intermittent operation allows a dramatic reduction in water consumption.
- Less risk of disease.

Disadvantages

- Limited frost mitigation down to -3°C (26.6°F).
- Limited effect under windy conditions

Under-tree frost mitigation must meet the following conditions:

- The entire area shall be irrigated.
- All land must be covered with weeds. The more weeds available, the larger the surface area, and thus the greater the heat transfer.
- The system must be fully automated, with a controller for the electrical valves of alternate irrigation sectors.
- An electronic sensor must be placed at a height not exceeding 50 cm (1.65 feet) above ground level to measure air temperature.

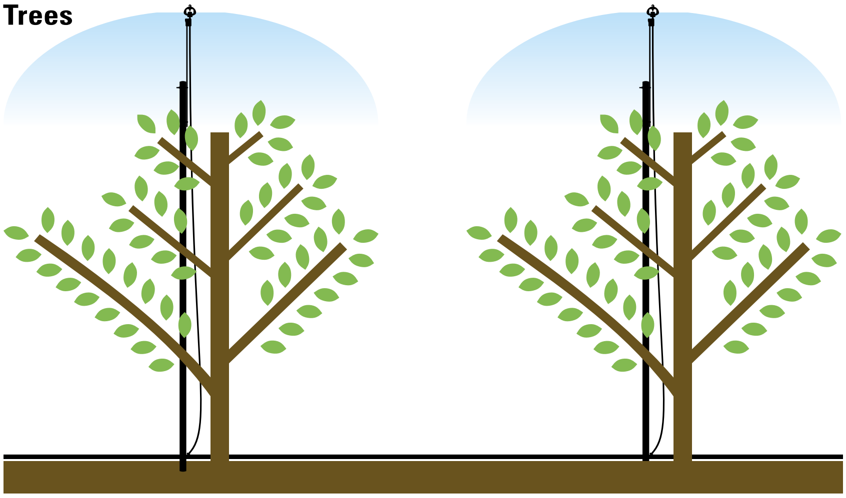
FROST MITIGATION BY IRRIGATION

Localized irrigation with over-crop sprinklers

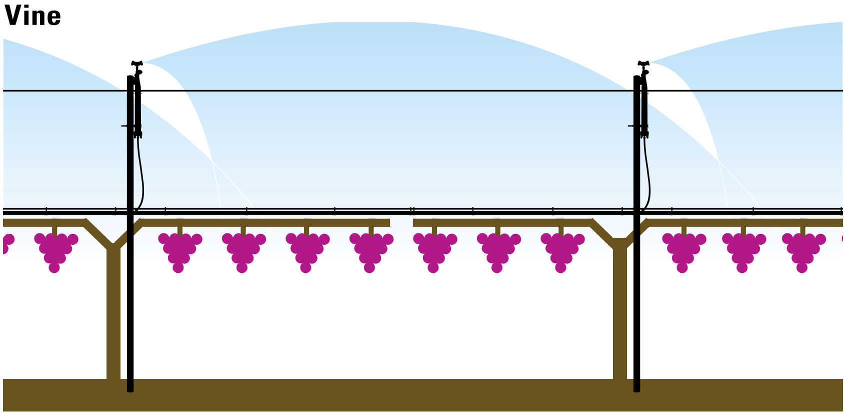
Localized irrigation during a frost event, with over-crop sprinklers maintains the melting heat targeting the crop only.

- Saves water.
- Protects buds and flowers with transparent ice.
- Continuous ice formation produces enough heat to maintain buds, flowers or fruits a safe, above-critical temperature.
- Protects the crop only, leaving the passages dry.
- Requires permanent irrigation.

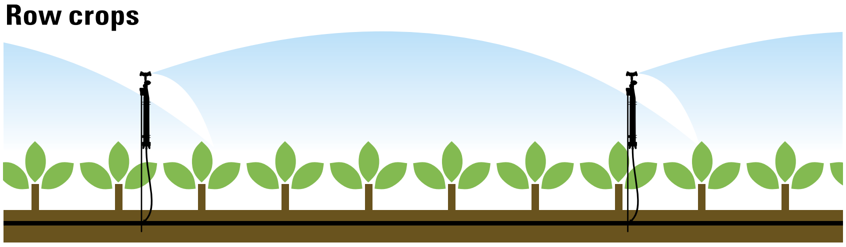
Trees



Vine



Row crops



Properties

- Provides efficient frost mitigation down to -5°C (23°F) in the watered area, with a 3 mm/h precipitation rate.
- Frost mitigation down to -8°C (17.6°F) can be obtained in the watered area with an increased precipitation rate.
- Supplies adequate water supply in accordance with the freezing level of crops and their stage of growth.
- Irrigation targets the crop only.
- Requires continuous irrigation during the period of protection.
- A reliable sprinkler is required.
- Special attention to cooling is required, due to evaporation.
- Do not stop sprinkling too soon. (See To water or not?, page 20).

Advantages

- Reduction (of 30%-70%) of water application compared with full coverage over-crop sprinkling.
- Better water distribution concentrated on the crop only.
- Low water consumption.
- Low energy consumption.
- More water per protected zone - greater protection.
- Covers sensitive parts of the crop.
- The required water storage is smaller than with full-coverage over-crop sprinkling.
- Intermittent operation allows a dramatic reduction in water consumption.

Disadvantages

- Evaporation risk (in case of low humidity and wind).
- Proper timing of start and end of irrigation is critical.
- The system must work continuously for many hours.
- Limited efficiency in windy conditions.
- Requires finer filtering (130 micron/120 mesh).

FROST MITIGATION BY IRRIGATION

To water or not?

ATTENTION

Be prepared to accept the responsibility of whether to water or not and to allow water to flow.

- Be ready to turn on the frost mitigation system whenever the forecast indicates a temperature approaching 0°C (32°F).
- Consider air humidity, dew points and wind. On a clear night with low humidity, be prepared to turn on the frost mitigation system at slightly higher temperatures [about 2°C (34°F)].

WARNING

If the forecast is borderline - with dry air, low dew points and wind above 8 km/h (5 mph) - irrigation might cause more damage to the crop than not applying frost mitigation at all.

The damage in this situation would be caused by evaporative cooling, which can make the crop colder than it would have been if no water had been applied.

The decision concerning the times to start and stop the sprinklers for frost mitigation should be based on both temperature and humidity in the orchard.

The opening and closing temperatures are critical. The frost mitigation sprinklers must always be started and stopped when the wet bulb temperature is above the critical temperature of damage to the crop.

When should irrigation be started?

When the temperature of the wet bulb approaches 0°C (32°F). It is safe to start irrigation at slightly higher temperatures [about 2°C (34°F)].

When a sprinkler system is started, the air temperature in the sprayed area drops down to the wet bulb temperature due to evaporation. Naturally, this initial drop is followed by an increase in temperature, as the water freezes on the ground and on parts of plants when heat is released and warms the air.

However, if the dew point temperature is low, the wet bulb temperature may be considerably lower than the air temperature and the initial drop in temperature may damage the crop.

No two situations are alike. As a rule of thumb, the frost mitigation process must start before the temperature reaches 2°C (34°F) at the sprinkler jet. However, in the presence of microclimate areas it may be necessary to start watering at slightly higher temperatures.

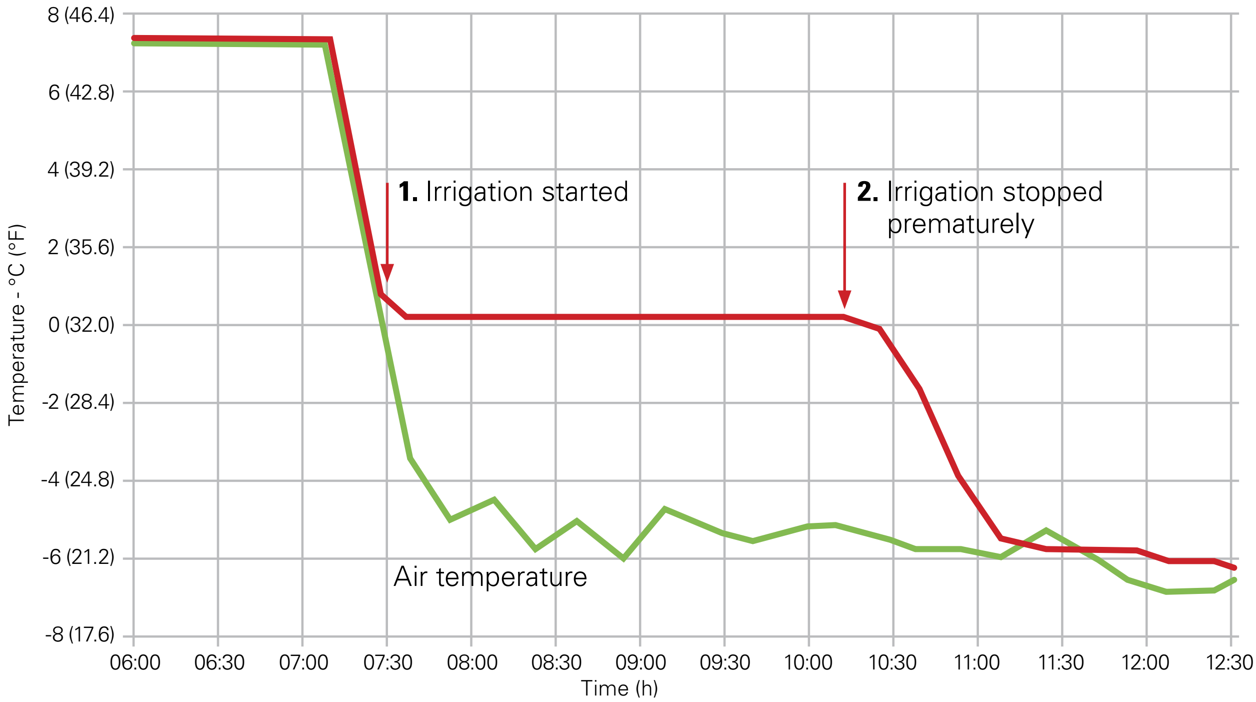
ATTENTION

Start watering early, before the temperature dips low enough to freeze the sprinkler's jets; after that, the system will not be operable.

A system with multiple pumps takes more time to turn on. Therefore, it must be operated in advance to assure that the whole system is running before the temperature reaches 2°C (34°F) at the sprinkler jet.

EXAMPLE

The effect of over-crop sprinkling



1. Irrigation is started

The temperature is kept above the critical level and the crop is protected.

2. Irrigation is stopped prematurely

The temperature drops to the ambient air temperature and the crop is no longer protected.

When should irrigation be ended?

Over-crop sprinkling

Only when all the ice on the plant is melted, regardless of the temperature or the RH.

WARNING

If irrigation is ended before all the ice on the plant is melted, the remaining ice on the plant will draw heat from the plant, cooling it further. The plant temperature will fall below the critical temperature, causing significant damage to its tissues.

Under-tree sprinkling

When the temperature indicated by the dry bulb thermometer is above the protected range.

Even if the sun is shining on the plants and the air temperature is above melting point (0°C or 32°F), sprinklers should not be stopped unless the wet bulb temperature is above the critical temperature of damage.

If soil flooding is not a problem, allow the wet bulb temperature to rise above melting point (0°C or 32°F) before stopping the sprinklers, to add an extra measure of security.

In most cases it is not necessary to wait until all the ice is melted to shut off the water. In many cases the system can be shut off safely before the ice is completely melted - often at 1.5°C (35°F) or 3°C (37°F).

SELECTING A SYSTEM

Introduction

The proper selection of a frost mitigation system is a crucial issue. First and foremost, it is an economic issue. The aim is to provide sufficient protection of the crop, ensuring a regular harvest in terms of quantity and quality considering the system set-up and current operational costs vs. the potential cost of the damage avoided.

In order to select the appropriate frost mitigation system, one must take into consideration:

- Water availability
- Energy availability
- The size of the protected area
- The meteorological properties of the site
- The site topography and its particular microclimate spots
- The expected frequency of frost events
- The expected duration of a typical frost event
- The distance between trees/rows and the diameter of the trees (for localized coverage)
- The critical temperature of the plant in each of its growth phases

Netafim™ frost mitigation products

Netafim™ offers a variety of sprinkler, micro-sprinkler and micro-emitter systems, that are suitable for frost mitigation, all with high resistance to clogging and highly uniform distribution.

MegaNet™

- Total coverage
- High (24°) and low (15°) trajectory
- Road protection (180°) - optional
- Insect-proof

SuperNet™

- Total or localized coverage
- Flow regulation
- Insect-proof

GyroNet™

- Total or localized coverage
- Relatively low working pressure
- Insect-proof

SELECTING A SYSTEM

Pulsar™

The Pulsar™ is an innovative pressure-compensated intermittent emitter that distributes relatively small amounts of water over a large wetted area, maintaining uniform dispersion. It supplies continuous and uniform irrigation at low flow rates - 8/12/15/20 l/h - using micro-emitters originally designated for higher flow rates.

Pulsar™ with StripNet™

- Flow regulation
- Strip area protection
- Highly efficient water consumption

Pulsar™ with GyroNet™

- Flow regulation
- Total or localized coverage
- Insect-proof
- Highly efficient water consumption

Frostie

A frost-mitigation controller that automates the task of monitoring temperature and humidity.

When Frostie preset thresholds are crossed, an alarm is triggered.

The alarm may use a solenoid or relay output to activate misters, sprinklers or other protective equipment.

See further information regarding Netafim™ frost mitigation products at http://www.netafim.com/irrigation-products-technical-materials.

SELECTING A SYSTEM

Netafim™ offers a wide range of emitters for total and localized coverage

MegaNet™

Nominal flow rate (l/h)	Recommended working pressure (bar)	Effective wetted diameter (m)*	
		24D	15D
200	2.0 - 3.0	12.0	14.0
250		13.0	14.0
350		14.0	14.0
450		16.0	14.0
550		17.0	14.0
650		17.0	15.0
750		17.0	16.0

*The wetted diameter varies according to the height of the emitter above the ground/crop.
The background shading of each cell indicates the emitter's lockpin color code.

SuperNet™

Nominal flow rate (l/h)	Recommended working pressure (bar)	Effective wetted diameter (m)*				
		LR	SR	SRD	SSR	GS
20	1.5 - 4.0	4.5	2.5	1.8		
30		6.0	3.5	1.8	2.0	
35		6.0	3.5	1.8	2.0	
40		6.0	3.5	1.8	2.5	
50		7.0	4.5	1.8		
58		7.0	4.5	1.8		
70		7.0	5.0	1.8		
90		7.0	5.0	2.0		7.5
110	2.0 - 4.0	8.0	6.5	2.0		8.0

GyroNet™

Nominal flow rate (l/h)	Recommended working pressure (bar)	Effective wetted diameter (m)*			
		LR	SR	SRD	SSR
27	1.5 - 2.5	4.0	3.5	1.3	2.0
40		5.5	4.5	1.3	2.5
58		7.0	5.0	1.3	3.5
70		7.0	5.5	1.3	4.0
90		7.0	6.0	1.3	
120		8.0	6.5	1.3	
150		8.5	7.0	2.5	
200		9.5	8.5	2.5	
250		10.0	8.5	3.5	
300		11.0	8.5	3.5	

*The wetted diameter varies according to the height of the emitter above the ground/crop.
The background shading of each box indicates the emitter's rotor color code.

Recommended configurations for over-tree localized coverage

There are many configurations for frost mitigation with over-tree localized coverage. The tables below present the most common configurations for various treetop diameters and minimum required flow rates.

For 3.0 mm/h minimum required precipitation rate

Treetop diameter (m)	Treetop area (m²)	Minimum required flow rate (l/h)	Recommended sprinkler head	Calculated precipitation rate (mm/h)
1.0	0.8	2.4	Pulsar™ 8 l/h with GyroNet™ SSR	4.5
1.5	1.8	5.3	Pulsar™ 8 l/h with GyroNet™ SSR	4.5
2.0	3.1	9.4	Pulsar™ 12 l/h with GyroNet™ SSR	3.8
2.5	4.9	14.7	Pulsar™ 15 l/h with GyroNet™ SRD	3.1
3.0	7.1	21.2	Pulsar™ 20 l/h with GyroNet™ SRD	2.8
3.5	9.6	28.9	SuperNet™ SR 30 l/h	3.1
4.0	12.6	37.7	SuperNet™ SR 40 l/h	3.2
4.5	15.9	47.7	SuperNet™ SR 50 l/h	3.1
5.0	19.6	58.9	SuperNet™ SR 70 l/h	3.0
5.5	23.8	71.3	GyroNet™ SR 70 l/h	2.9
6.0	28.3	84.8	GyroNet™ SR 90 l/h	3.2

NOTE

Recent performance trials have demonstrated that adequate frost mitigation can be achieved at precipitation rates lower than 3.0 mm/h. Precipitation rates of 2.5 or even 2.0 mm/h may suffice. A cautious selection of the required precipitation rate can result in substantial savings - for example, a 2.0 mm/h system saves about 33% on water consumption compared with a 3.0 mm/h system. Considering the reduced cost of infrastructure - piping, valves, pumps and filters - due to reduced flow rate requirements and the reduced energy cost due to smaller pump requirements, this is an important consideration.

For 2.5 mm/h minimum required precipitation rate

Treetop diameter (m)	Treetop area (m²)	Minimum required flow rate (l/h)	Recommended sprinkler head	Calculated precipitation rate (mm/h)
1.0	0.8	2.0	Pulsar™ 8 l/h with GyroNet™ SSR	4.5
1.5	1.8	4.4	Pulsar™ 8 l/h with GyroNet™ SSR	4.5
2.0	3.1	7.9	Pulsar™ 8 l/h with GyroNet™ SRD	2.5
2.5	4.9	12.3	Pulsar™ 15 l/h with GyroNet™ SRD	3.1
3.0	7.1	17.7	Pulsar™ 20 l/h with GyroNet™ SRD	2.8
3.5	9.6	24.1	Pulsar™ 25 l/h with GyroNet™ SSR	2.6
4.0	12.6	31.4	GyroNet™ SR 40 l/h	2.5
4.5	15.9	39.8	GyroNet™ SR 40 l/h	2.5
5.0	19.6	49.1	GyroNet™ SR 58 l/h	3.0
5.5	23.8	59.4	GyroNet™ SR 70 l/h	2.9
6.0	28.3	70.7	GyroNet™ SR 90 l/h	3.2

For 2.0 mm/h minimum required precipitation rate

Treetop diameter (m)	Treetop area (m²)	Minimum required flow rate (l/h)	Recommended sprinkler head	Calculated precipitation rate (mm/h)
1.0	0.8	1.6	Pulsar™ 8 l/h with GyroNet™ SSR	4.5
1.5	1.8	3.5	Pulsar™ 8 l/h with GyroNet™ SSR	4.5
2.0	3.1	6.3	Pulsar™ 8 l/h with GyroNet™ SRD	2.5
2.5	4.9	9.8	Pulsar™ 12 l/h with GyroNet™ SRD	2.4
3.0	7.1	14.1	Pulsar™ 20 l/h with GyroNet™ SR - UD*	2.1
3.5	9.6	19.2	Pulsar™ 20 l/h with GyroNet™ SR - UD*	2.1
4.0	12.6	25.1	GyroNet™ SR 40 l/h	2.5
4.5	15.9	31.8	GyroNet™ SR 40 l/h	2.5
5.0	19.6	39.3	GyroNet™ SR 58 l/h	3.0
5.5	23.8	47.5	GyroNet™ SR 70 l/h	2.9
6.0	28.3	56.5	GyroNet™ SR 90 l/h	3.2

*UD = Upside-down installation

Recommended sprinkler heads for localized coverage of vine and row crops

For 3.0 mm/h minimum required precipitation rate

Distance between emitters (m)	Wetted area per emitter (m²)	Minimum required flow rate (l/h)	Recommended sprinkler head	Calculated precipitation rate (mm/h)
5.0	2.5	7.5	Pulsar™ 12 l/h with StripNet™ 1AN	4.8
6.0	3.0	9.0	Pulsar™ 12 l/h with StripNet™ 2AN	4.0
7.0	3.5	11.5	Pulsar™ 12 l/h with StripNet™ 2AN	3.4

Selecting the frost mitigation scheme

The proposed schemes:

Over-crop sprinkling
- Total coverage over trees
- Localized coverage over trees
- Total coverage over row crop
- Localized coverage over row crop

Provides efficient frost mitigation down to -5°C with a 3 mm/h precipitation rate.
Frost mitigation down to -8°C can be obtained with an increased precipitation rate.

Under-tree sprinkling total coverage

Provides efficient frost mitigation down to -3°C with a 3 mm/h precipitation rate.

For further details see Frost mitigation schemes, page 16.

For a comparison of the water and energy consumption of the different frost mitigation schemes, see Total coverage vs. localized coverage in trees, page 31,
and Total coverage vs. localized coverage in vine or row crops, page 34,

SELECTING A SYSTEM

Calculations

Conversions and units

Area	1 hectare (ha) = 10,000 square meter (m^2)
Distance	1 millimeter (mm) = 0.001 meter (m)
Volume	1 cubic meter (m^3) = 1,000 liter (l)

Pressure head	1 bar = 10 meter (m)
Power	1 hp X 0.75 = 1 kW
Radius	= diameter / 2
Pi (π)	= 3.14

NOTE

The calculations in the following examples are simplified. The constants used are approximate, the assumed pump efficiency is 74% and head losses (due to pumping depth, piping, valves, topographic characteristics, etc.) have been ignored in order to facilitate computation when comparing different system schemes.

Water and energy (electricity/fuel) supply for frost mitigation

- The average duration of a single frost event is 8-10 hours.
- A second frost event can occur within 24 hours from the first one.
- Over-crop irrigation must not be interrupted during a frost event.

ATTENTION

Sufficient water and energy supply for frost mitigation must be ensured for the entire duration of 2 consecutive frost events.

Calculations for over- or under-tree total coverage

Select the appropriate emitter considering the following parameters:

Over-crop sprinkling

- Type of crop and its critical temperature in each growth stage.
- Performance limitations of the existing emitters present for current irrigation, in order to check their suitability for frost mitigation.
- The working pressure (bar) of the existing irrigation system, to consider the possibility of using the existing infrastructure for frost mitigation with dedicated emitters or by temporarily raising the existing emitters above the trees when frost events are expected, or the required working pressure (bar) of the planned frost mitigation system.
- Quantity of emitters per area for distribution uniformity, in order to achieve the required precipitation rate.

WARNING

Make sure that the quantity of water reqired for continuous irrigation throughout the entire duration of the frost event is available.

Under-tree sprinkling

- Type of crop and its critical temperature in each growth stage.
- The working pressure (bar) of the existing irrigation system, to consider the possibility of using the existing infrastructure for frost mitigation, or the required working pressure (bar) of the planned frost mitigation system.
- Possibility of automation and design of a maximum of 3-shift irrigation areas, 2 minutes each shift.

WARNING

The control tubing of the valves must be insulated to prevent freezing when idle.

- Tree trunk density, in order to plan the layout of the frost mitigation system considering obstructions.
- Available height under the trees (cm).
- Emitter's delivery angle (degrees), in order to select the appropriate emitter considering the available height under the trees so that the irrigation does not wet the foliage.

EXAMPLE A

Total coverage

Where

- The minimum required precipitation rate = 3 mm/h
- The plantation covers 50 ha

Required water consumption per hectare

Multiply the area of 1 hectare in square meters (10,000 m²) by the minimum required precipitation rate (3 mm/h).

10,000 X 0.003 = 30 m³/h/ha

Select the appropriate emitter according to the tables on page 24

In this case, the MegaNet™ 450 l/h emitter is selected.

- Distances between emitters: 12 X 12 m
- Each emitter covers an area of 144 m²
- Recommended working pressure: 2.0 to 3.0 bar at the sprinkler head

NOTE

- Under-tree sprinkling using the MegaNet™ 450 l/h emitter provides efficient frost mitigation down to -3°C with a 3 mm/h precipitation rate. There is no known method for frost mitigation with under-tree sprinkling for temperatures below -3°C.
- Over-tree sprinkling using the MegaNet™ 450 l/h emitter provides efficient frost mitigation down to -5°C with a 3 mm/h precipitation rate. Frost mitigation down to -8°C can be obtained using Netafim™ emitters with higher flow rates, or by positioning the emitters closer to one another.

Number of emitters per hectare

Divide the area of 1 hectare in square meters (10,000 m²) by the area covered by a single emitter (144 m²)

10,000 / 144 = 69 emitters per hectare

Actual water consumption per hectare

Multiply the emitter's nominal flow rate (450 l/h) by the number of emitters per hectare (69).

69 X 450 = 31,050 l/h/ha

Convert the result to m³/h/ha.

31,050 / 1000 = 31.05 m³/h/ha

Total water consumption

Multiply the actual water consumption per hectare (31.05 m³/h/ha) by the number of hectares in the plantation (50).

31.05 X 50 = 1,552 m³/h

Select a pump with a flow capacity of 1,552 m³/h under a 25 m (2.5 bar) pressure head.

Energy consumption (kW)

- q = flow capacity (m³/h) = 1,552 m³/h
- P_h = pressure head (m) = 25 m
- C (constant) = 270

Multiply the flow capacity (1,552 m³/h) by the pressure head (25 m) and divide by the constant (270).

1,552 X 25 / 270 = 143 kW

Energy consumption (hp)

- q = flow capacity (m³/h) = 1,552 m³/h
- P_h = pressure head (m) = 25 m
- C (constant) = 200

Multiply the flow capacity (1,552 m³/h) by the pressure head (25 m) and divide by the constant (200).

1,552 X 25 / 200 = 194 hp

Calculations for over-tree localized coverage

Select the appropriate emitter considering the following parameters:

- Treetop diameter
- Calculated overall wetted treetop area
- Calculated required flow rate per tree

NOTE
The water and energy consumption of localized over-crop frost mitigation in trees is dependent on the distance between the trees in the same row, the distance between rows and the diameter of each tree. The further apart and the smaller diameter the trees are, the greater the savings in water and energy consumption compared with total coverage.

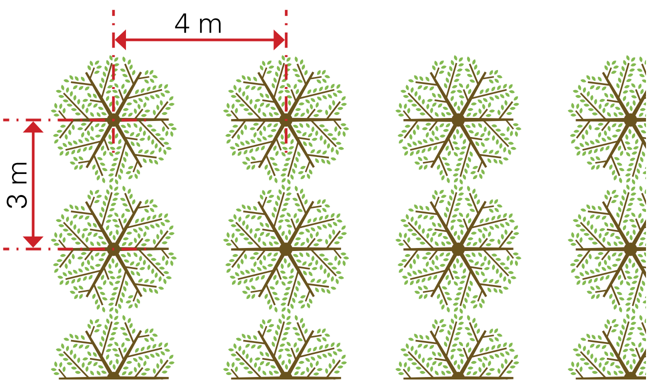
NOTE
For over-tree irrigation, in some cases a single emitter can be used for irrigating 2 adjacent trees (consult your Netafim™ local representative).

EXAMPLE B

Over-tree localized coverage

Where

- The minimum required precipitation rate = 3 mm/h
- The treetop diameter is 3 meter
- The trees are 3 meters apart in each row and the rows are 4 meters apart
- The plantation covers 50 ha



NOTE
When calculating the precipitation rate, consider each tree as a separate area.

The treetop area of each tree
Square the treetop radius (1.5) and multiply by π (3.14)

1.5^2 X 3.14 = 7 m^2

The required flow rate for each tree
Multiply the required precipitation rate (3 mm/h) by the treetop area (7 m^2).

7 X 3 = 21 l/h

Number of trees per hectare
Divide the area of 1 hectare in square meters (10,000 m^2) by the distance between adjacent trees in the same row (3 m) and by the distance between adjacent rows (4 m).

10,000 / (3 X 4) = 833 trees per hectare, one emitter per tree

Select the appropriate emitter according to the table for the 3.0 mm/h minimum required precipitation rate, page 25
In this case, the SuperNet™ SR 30 l/h emitter is selected.

- Calculated precipitation rate: 4.2 mm/h
- Recommended working pressure: 1.5 to 4.0 bar at the sprinkler head

Actual water consumption per hectare
Multiply the emitter's nominal flow rate (30 l/h) by the number of trees per hectare (833).

30 X 833 = 24,990 l/h/ha
Convert the result to m^3/h/ha.

24,990 / 1000 = 25 m^3/h/ha

Total water consumption

Multiply the actual water consumption per hectare ($25\ m^3/h/ha$) by the number of hectares in the plantation (50).

25 X 50 = 1,250 m³/h

Select a pump with a flow capacity of 1,250 m³/h under a 20 m (2.0 bar) pressure head.

Energy consumption (kW)

- q = flow capacity (m^3/h) = 1,250 m^3/h
- P_h = pressure head (m) = 20 m
- C (constant) = 270

Multiply the flow capacity (1,250 m^3/h) by the pressure head (20 m) and divide by the constant (270).

1,250 X 20 / 270 = 93 kW

Energy consumption (hp)

- q = flow capacity (m^3/h) = 1,250 m^3/h
- P_h = pressure head (m) = 20 m
- C (constant) = 200

Multiply the flow capacity (1,250 m^3/h) by the pressure head (20 m) and divide by the constant (200).

1,750 X 20 / 200 = 125 hp

EXAMPLE C

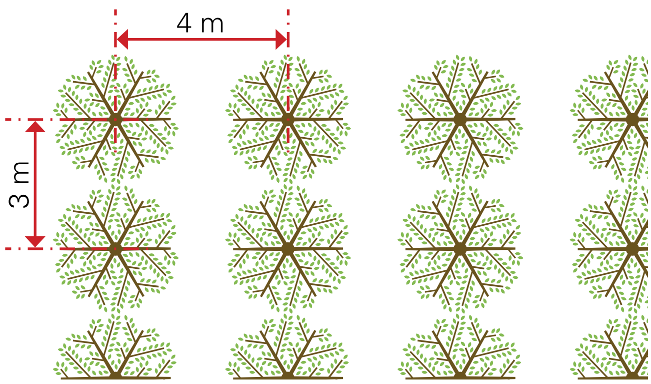
Intermittent over-tree localized coverage

NOTE

The main advantage of intermittent irrigation using the Pulsar™ is with localized frost mitigation.

Where

- The minimum required precipitation rate = 3 mm/h
- The treetop diameter is 3 meter
- The trees are 3 meters apart in each row and the rows are 4 meters apart
- The plantation covers 50 ha



NOTE

When calculating the precipitation rate, consider each tree as a separate area.

The treetop area of each tree

Square the treetop radius (1.5) and multiply by π (3.14).

1.5^2 X 3.14 = 7 m^2

The required flow rate for each tree

Multiply the required precipitation rate (3 mm/h) by the treetop area (7 m^2).

7 X 3 = 21 l/h

Number of trees per hectare

Divide the area of 1 hectare in square meters (10,000 m^2) by the distance between adjacent trees in the same row (3 m) and by the distance between adjacent rows (4 m).

10,000 / (3 X 4) = 833 trees per hectare, one emitter per tree

Select the appropriate emitter according to the table for 3.0 mm/h minimum required precipitation rate, **page 25**

In this case, the Pulsar™ 20 l/h with the GyroNet™ SRD emitter is selected.

- Calculated precipitation rate: 2.8 mm/h
- Recommended working pressure: 2.5 bar at the sprinkler head

Actual water consumption per hectare

Multiply the emitter's nominal flow rate (20 l/h) by the number of trees per hectare (833).

20 X 833 = 16,600 l/h/ha

Convert the result to $m^3/h/ha$.

16,600 / 1000 = 16.6 $m^3/h/ha$

Total water consumption
Multiply the actual water consumption per hectare (16.6 $m^3/h/ha$) by the number of hectares in the plantation (50).

16.6 X 50 = 830 m^3/h

Select a pump with a flow capacity of 830 m^3/h under a 25 m (2.5 bar) pressure head.

Energy consumption (kW)
- q = flow capacity (m^3/h) = 830 m^3/h
- P_h = pressure head (m) = 25 m
- C (constant) = 270

Multiply the flow capacity (830 m^3/h) by the pressure head (25 m) and divide by the constant (270).

830 X 25 / 270 = 77 kW

Energy consumption (hp)
- q = flow capacity (m^3/h) = 830 m^3/h
- P_h = pressure head (m) = 25 m
- C (constant) = 200

Multiply the flow capacity (830 m^3/h) by the pressure head (25 m) and divide by the constant (200).

830 X 25 / 200 = 104 hp

Total coverage vs. localized coverage in trees

Comparison of water and energy consumption

The table below presents a comparison of the water and energy consumption in the examples above.

Trees

Example	A - Total coverage	B - Localized coverage over-tree		C - Intermittent localized coverage over-tree	
	Consumption	Consumption	Saving*	Consumption	Saving*
Water ($m^3/h/ha$)	31.05	25.00	20%	16.60	47%
Energy (kW)	143.0	93.0	35%	77.0	46%

*Compared with total coverage.

Reasons to prefer localized coverage to total coverage

- Savings of up to 70% on water (depending on the specific setup, the distance between trees in the same row, the distance between adjacent rows, the treetop diameter, etc.).
- Reduced cost of infrastructure - piping, valves, pumps and filters due to reduced flow rate requirement.
- Savings of up to 70% on energy due to smaller pump requirement.
- Another advantage of localized coverage: Where frost mitigation is applied to selected parts of the area (see Microclimate, page 10), or in cases of water supply, energy or infrastructure constraints, the same infrastructure can provide a larger area with a sufficient flow rate for effective frost mitigation.

Calculations for vine and row crop total coverage

Select the appropriate emitter considering the following parameters:

- Type of crop and its critical temperature in each growth stage.
- Performance limitations of the existing emitters used for current irrigation, in order to check their suitability for frost mitigation.
- The working pressure (bar) of the existing irrigation system, to consider the possibility of using the existing infrastructure for frost mitigation with dedicated emitters or temporarily raising the existing emitters above the trees when frost events are expected, or the required working pressure (bar) of the planned frost mitigation system.
- Quantity of emitters reqired per area for distribution uniformity and achievement of the required precipitation rate.

WARNING
Make sure that the quantity of water required for continuous irrigation throughout the entire duration of the frost event is available.

EXAMPLE D

Total coverage

Where

- The minimum required precipitation rate = 3 mm/h
- The plantation covers 50 ha

Required water consumption per hectare
Multiply the area of 1 hectare in square meters (10,000 m²) by the minimum required precipitation rate (3 mm/h).

10,000 X 0.003 = 30 m³/h/ha

Select the appropriate emitter according to the tables on **page 24**
In this case, the MegaNet™ 450 l/h emitter is selected.

- Distances between emitters: 12 X 12 m
- Each emitter covers an area of 144 m²
- Recommended working pressure: 2.0 to 3.0 bar at the sprinkler head

NOTE

- Over-crop sprinkling using the MegaNet™ 450 l/h emitter provides efficient frost mitigation down to -5°C with a 3 mm/h precipitation rate. Frost mitigation down to -8°C can be obtained using Netafim™ emitters with higher flow rates, or by positioning the emitters closer to one another.

Number of emitters per hectare
Divide the area of 1 hectare in square meters (10,000 m²) by the area covered by a single emitter (144 m²).

10,000 / 144 = 69 emitters per hectare

Actual water consumption per hectare
Multiply the emitter's nominal flow rate (450 l/h) by the number of emitters per hectare (69).

69 X 450 = 31,050 l/h/ha

Convert the result to m³/h/ha.

31,050 / 1000 = 31.05 m³/h/ha

Total water consumption
Multiply the actual water consumption per hectare (31.05 m³/h/ha) by the number of hectares in the plantation (50)

31.05 X 50 = 1,552 m³/h

Selected a pump with a flow capacity of 1,552 m³/h under a 25 m (2.5 bar) pressure head.

Energy consumption (kW)

- q = flow capacity (m³/h) = 1,552 m³/h
- P_h = pressure head (m) = 25 m
- C (constant) = 270

Multiply the flow capacity (1,552 m³/h) by the pressure head (25 m) and divide by the constant (270).

1,552 X 25 / 270 = 143 kW

Energy consumption (hp)

- q = flow capacity (m³/h) = 1,552 m³/h
- P_h = pressure head (m) = 25 m
- C (constant) = 200

Multiply the flow capacity (1,552 m³/h) by the pressure head (25 m) and divide by the constant (200).

1,552 X 25 / 200 = 194 hp

SELECTING A SYSTEM

Calculations for vine and row crop localized coverage

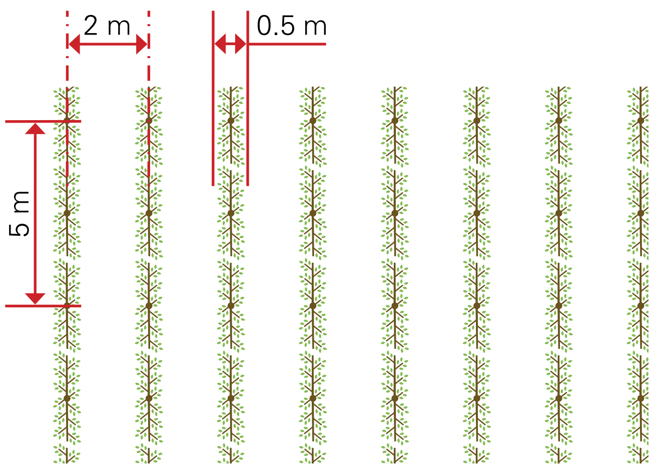
NOTE
The main advantage of intermittent irrigation using the Pulsar™ is with localized frost mitigation.

Select the appropriate emitter considering the following parameters:
- Wetted area per emitter
- Calculated overall wetted row area
- Calculated required flow rate per emitter

NOTE
Water and energy consumption of frost mitigation in vineyards and row crops is dependent on the distance between rows. The further apart the rows, the greater the savings in water and energy consumption compared with total coverage.

EXAMPLE E
Localized coverage

Where
- The minimum required precipitation rate = 3 mm/h
- The distance between emitters in the same row is 5 meters
- The distance between rows is 2 meters
- The plantation covers 50 ha



Area irrigated by each emitter
Multiply the length of the irrigated area by each emitter (5 m) by its width (2.5 m).

$$5 \times 0.5 = 2.5\ m^2$$

Minimum required flow rate of each emitter
Multiply the required precipitation rate (3 mm/h) by the irrigated area by each emitter (2.5 m^2).

$$3 \times 2.5 = 7.5\ l/h$$

Number of emitters per hectare
Divide the area (10,000 m^2) by the multiplication of the distance between emitters in the same row (5 m) by the distance between rows (2 m).

$$10{,}000 / (5 \times 2) = 1{,}000 \text{ emitters per hectare}$$

Select the appropriate emitter according to the table, Recommended sprinkler heads for vine and row crops localized coverage, on **page 26**
In this case, the Pulsar™ 12 l/h with the StripNet™ 1AN emitter is selected.
- Calculated precipitation rate: 4.8 mm/h
- Recommended working pressure: 2.5 bar at the Pulsar™ inlet

Actual water consumption
Multiply the emitter's nominal flow rate (12 l/h) by the number of emitters per hectare (1,000).

$$12 \times 1{,}000 = 12{,}000\ l/h/ha$$

Convert the result to $m^3/h/ha$.

$$12{,}000 / 1000 = 12\ m^3/h/ha$$

Total water consumption
Multiply the actual water consumption per hectare (12 $m^3/h/ha$) by the number of hectares in the plantation (50).

$$12 \times 50 = 600\ m^3/h$$

Select a pump with a flow capacity of 600 m^3/h under a 25 m (2.5 bar) pressure head.

Energy consumption (kW)

- q = flow capacity (m^3/h) = 600 m^3/h
- P_h = pressure head (m) = 25 m
- C (constant) = 270

Multiply the flow capacity (600 m^3/h) by the pressure head (25 m) and divide by the constant (270).

600 X 25 / 270 = 55.5 kW

Energy consumption (hp)

- q = flow capacity (m^3/h) = 600 m^3/h
- P_h = pressure head (m) = 25 m
- C (constant) = 200

Multiply the flow capacity (600 m^3/h) by the pressure head (25 m) and divide by the constant (200).

600 X 25 / 200 = 75 hp

Total coverage vs. localized coverage in vine or row crops

Comparison of water and energy consumption

The table below presents a comparison of the water and energy consumption in the examples above.

Vine or row crops

Example	D - Total coverage	E - Intermittent localized coverage over row crop	
	Consumption	Consumption	Saving*
Water ($m^3/h/ha$)	31.05	12.00	61%
Energy (kW)	143.0	55.5	61%

*Compared with total coverage.

Reasons to prefer localized coverage to total coverage

- Savings of up to 70% on water (depending on the specific setup, the distance between emitters in the same row, the distance between adjacent rows, etc.).
- Reduced cost of infrastructure - piping, valves, pumps and filters due to reduced flow rate requirement.
- Savings of up to 70% on energy due to smaller pump requirement.
- Another advantage of localized coverage: Where frost mitigation is applied to selected parts of the area (see Microclimate, page 10), or in cases of water supply, energy or infrastructure constraints, the same infrastructure can provide a larger area with a sufficient flow rate for effective frost mitigation.

SUCCESS STORIES

This chapter presents 7 actual cases of frost events, the system installed at each site, the results and the client's comments.

These testimonials give us the confidence to wholeheartedly recommend frost mitigation by irrigation. It is actually the most efficient and beneficial frost mitigation method on the market.

We would be pleased to read more success stories. Farmers who own a Netafim™ system for frost mitigation by irrigation, and representatives of Netafim™ around the globe are warmly invited to send their stories to us at Dany.Feinberg@netafim.com

We will be happy to publish them in the next updated edition of this handbook.

Case No. 1

Stengaarden, Denmark

Site description
Christmas trees nursery
4 ha
GyroNet™ Turbo 250 l/h
Above the crop

Frost event
The frost event started at around 04:00 AM.
Minimum temperature in field during the frost event: -5°C (23°F).
The frost event lasted for 6 hours.
3 frost events occurred during the season.

Frost mitigation
The farmer preferred irrigation to other methods for the simple reason that he could use the same system to cool his strawberries in the summer.

The farmer chose the GyroNet™ Turbo 250 l/h, recommended by the local Netafim™ representative.

Solution
GyroNet™ Turbo 250 l/h, 6 x 7 meter (19.7 x 23 foot) spacing, total 1,000 sprinklers, semi-manual operation with one valve per ha, flow 60 m^3/h (15,850 GPH), controlled by Miracle Plus program, operating at 4 minutes per valve continuous cycle.

Results
There was only minimum damage (between 3% and 5%). The farmer is satisfied with his investment.

Conclusion
The farmer testifies: Success is easy, even when using simple head control.

SUCCESS STORIES

Case No. 2

Annton Nursery, Cambridge, New Zealand

Site description
Plant and tree nursery
SuperNet™ GS 110 l/h
Above the crop

Frost event
The farm experienced numerous frost events over the last 6 years including a -4°C (24.8°F) frost in June 2015.

Frost mitigation
Hothouse incorporating a propagation shed and a growing area.
Controlled by an NMC Pro Irrigation controller working in conjunction with an NMC Junior controller for frost mitigation.
Frost sensing - a Mist Guard is situated in the open growing area and the NMC Junior controller responds to its input with a conditional program.
2 zones are irrigated in alternating 1-minute rounds until the frost condition ends.

Solution
SuperNet™ GS 110 l/h on 1.2 m stand
Spacing: 4 x 4 m
Application rate: 6 mm average

Results and Conclusion
This is a very successful frost mitigation scheme in NZ and the client is very happy with the level of protection achieved.

Case No. 3

Voivodina, Serbia

Site description
Apple orchard
120 ha
SuperNet™ LR 20 l/h
Under the canopy

Frost event
The frost event started at around 01:00 AM.
Minimum temperature in field during the frost event: -3°C (26.6°F).
The frost event lasted for 5 hours.
It was a sporadic frost event.

Frost mitigation
According to the recommendation of the local Netafim™ representative and in light of a limited water supply, the SuperNet™ LR 20 l/h emitter was chosen.

Conclusion
The farmer is satisfied with the results.

SUCCESS STORIES

Case No. 4

Bredemosegaard, Denmark

Site description
Cherry orchard
6 ha
MegaNet™ 24D 200 and 250 l/h
Above the crop

Frost event
The frost event started at around 04:00 AM.
Minimum temperature in field during the frost event: -5°C (23°F).
The frost event lasted for 6 hours.
4 frost events with temperatures down to -5°C (23°F) occurred during 2015.

Frost mitigation
The farmer chose frost mitigation by irrigation, mainly because water was not an issue (plenty of free water, existing pump system). The MegaNet™ emitter was chosen due to its lower price compared with other emitters such as metal impact sprinklers.

Solution
MegaNet™ 24D 200 and 250 l/h, 8 x 10 meter (26.2 x 32.8 foot) spacing operating in one shift, manual start by farmer, flow 165 m^3/h (43,588 GPH)

Results and conclusion
After testing the system for two years - 2011 and 2012 - with positive results, the farmer invested in MegaNet™ sprinklers for the whole area. Since the operation is manual, it is assumed that some damage will occur. The farmer testifies that he returned the investment within the first two years of operation and therefore he considers the investment in the system a success.

The most important thing to learn from this project is NEVER to compromise with application rate and automatic operation supervised by the farmer.

Case No. 5

Hoogland, South Africa

Site description

Apples and pears (high-income crop in lower areas of the farm)
30 ha
980 m above sea level
MegaNet™ 24D 200 and 250 l/h on 4 to 5 m rows, above crop.
SuperNet™ 70 l/h on 3 to 4 m row spacing, at 2/3 the height of the tree.

Frost event

The frost event started between 22:00 PM and 02:00 AM.
Minimum temperature in field during the frost event: -3°C (26.6°F).
The frost event lasted for about 9 hours.
Frost events occur 4 to 5 times per year.

Frost mitigation

The farmer preferred frost mitigation by irrigation because other methods are very expensive and not as efficient.
The farmer chose this method by recommendation of the local Netafim™ representative.

Solution

Workers were sent to the field when the temperature dropped to 2.5°C (36.5°F).
The system was started when the temperature dropped to 2°C (35.6°F).
The system was started manually to ensure that it was working properly.
The system remained running until all the ice had melted.
Flow: about 20 m^3/ha.
30 ha x 20 m^3/ha/h = 600 m^3/h supplied by pump stations.
Single shift for the whole area.

Results

Damage avoided: Depending on time of frost, export of fruit may drop 60% to 100%, in which case the fruit is sold for juice.
Losses avoided: Yield 80 to 100 tons per ha of high-income crop.

Conclusion

The client feels that over-crop frost mitigation is a good protection policy. However, water supply limitations may affect expansion.

SUCCESS STORIES

Case No. 6

Mazaleon, Teruel, Spain

Site description
Peach orchard
2 ha
GyroNet™ LR 70 l/h
Above the crop

Frost event
The frost event started on March 19, 2009 at 01:00 AM.
The crop was in the vegetative state F (bloom).
Critical temperature -3°C (26.6°F).
Minimum temperature in field during the frost event: -5°C (23°F).
The frost event lasted for 6 hours.
3 frost events occurred during the season.

Frost mitigation
A micro-sprinkler system was chosen because it reduces water consumption by approximately half.

Solution
GyroNet™ LR 70 l/h, 6 x 4 meter (19.7 x 13.1 foot) spacing, emitters installed on 4-meter high wooden poles, located at the vertical center of the tree. Working pressure: 2.5 bar (36.3 PSI), flow rate: 4 mm/h (0.157 in/h) throughout the entire duration of the frost event.

The localized irrigation pattern prevents wetting of the roads and soil surface, while ensuring the protection of the foliage only, resulting in significantly lower water usage.

Results
Implementation of frost mitigation by irrigation allowed a harvest of 30 ton at a price of € 2/kg. A gross profit of € 60,000 was obtained. Without frost mitigation, the result would have been a negative gross profit.

Conclusion
The ice created must be transparent for the warming effect to take place.
The client is very satisfied with the results.

SUCCESS STORIES

Case No. 7

Vester Vedsted, Denmark

Site description

Vineyard
4 ha
Pulsar™ 12 l/h with StripNet™ head
Above the crop

Frost events

The system was installed during the winter of 2015 and was scheduled to start operating for frost mitigation during the spring season.

On April 20 the first frost event occurred unexpectedly and the frost controller started the system automatically around 05:00 AM at a temperature of around -3°C (26.6°F) and RH around 30%.

In total, there were 3 frost events this season, each lasting about 5 hours.

Frost mitigation

The farmer chose the Pulsar™ 12 l/h with StripNet™ head for two reasons.

1. Other methods such as burning tires or heating fans did not provide adequate results and involved too much work.

2. Any other system would require more water supply, and therefore a larger investment.

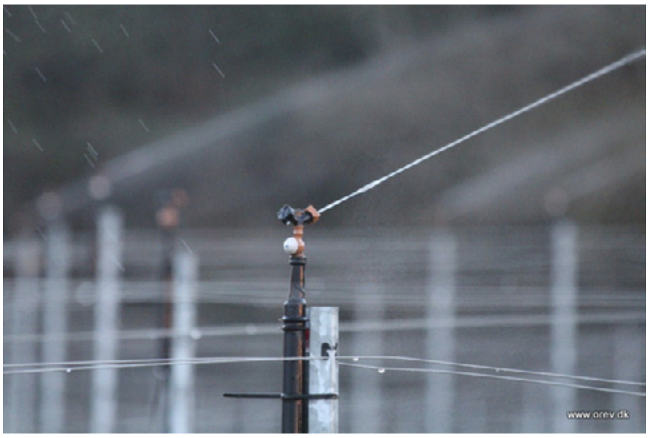
Solution

Pulsar™ 12 l/h with StripNet™ head, 4 meter (13.1 feet) spacing between emitters in the same row, 2,500 emitters operating in one shift.

Results and conclusion

On April 21, the farmer called the local Netafim™ representative - and said this was his best investment in years! He noted that next time, Netafim™ should ask a higher price for the system.

After three frost events, he concluded: Next to zero damage in the vineyard, while other growers in the area suffered 20% - 100% loss of yield.



SYSTEMS INSTALLED AROUND THE GLOBE

Netafim™ solutions for frost mitigation by irrigation are gaining increasing popularity around the world, due to their efficiency and profitability.

This chapter presents 4 actual Netafim™ systems for frost mitigation by irrigation among many installed at different sites around the globe.

Site No. 1

Casablanca Valley, Chile

Site description
Vineyard
5.7 ha frost mitigated by irrigation, out of 70 ha
Pulsar™ 12 l/h with StripNet™ emitter

Frost mitigation
Frost mitigation is provided in most of the vineyard by wind towers, but there are areas that the wind towers do not reach. In these areas, frost mitigation by irrigation was chosen.

The Pulsar™ 12 l/h with StripNet™ emitter was chosen by recommendation of a Netafim™ technical consultant.

Site No. 2

France

Site description
Kiwi
2.5 ha
SuperNet™ UD SR 35 l/h,
5 x 3 m under the crop for irrigation
SuperNet™ SR 70 l/h,
5 x 4 m under the crop for frost mitigation

Frost mitigation
Frost mitigation by irrigation was chosen after comparing its price to the price of wind towers. Wind towers were too expensive.

The SuperNet™ SR 70 l/h was chosen for its relatively low flow rate.

SYSTEMS INSTALLED AROUND THE GLOBE

Site No. 3

Italy

Site description
Apricot and peach
9.0 ha
Supernet LR 50 l/h
Under the canopy, every 2 m, 30 cm above ground

Frost mitigation
Frost mitigation by irrigation was chosen for its relatively low price and because it offers higher protection capacity for fruit trees compared with other methods.

The Supernet LR 50 l/h emitter was chosen because it is pressure compensated and has good uniformity.

Site No. 4

France

Site description
Kiwi biologic agriculture
8 ha
SuperNet™ LR 40 l/h,
5 x 3 m
UD, under the crop for irrigation
UR, above the crop for frost mitigation

Frost mitigation
Frost mitigation by irrigation was chosen after comparing its price to the price of wind towers. Wind towers were too expensive.

The SuperNet™ LR 40 l/h was chosen for its relatively low flow rate.

APPENDIX 1

Further reading

This appendix provides users with links to recommended complementary documents that discuss related subjects at length.
Download them at http://www.netafim.com/irrigation-products-technical-materials

Avoiding Frost Damage

Frost mitigation constitutes an integral component of deciduous plant cultivation in numerous regions throughout the world. This guide provides fundamental data and explanations for dealing with frost and frost mitigation. By means of professional articles, the guide presents and explains the principles and basic terms of the phenomenon and presents possible solutions. Numerous professional articles and data banks provide further information and explanations. We at Netafim™ have selected only a small part of the existing material, and will continue to publish more articles to expand the knowledge regarding this subject.

Micro-sprinklers, micro-emitters & sprinklers - Product catalog

The following catalog is an aid that provides basic data on each of the products at hands, reach.

1. Pressure compensated micro-sprinklers and micro-emitters.
2. Micro-sprinklers and micro-emitters.
3. Micro-sprinklers and micro-emitters upright stands complementary accessories.
4. Micro-emitters for nursery and pot irrigation.
5. Micro-sprinklers and micro-emitters for protected crops.
6. Micro-sprinklers and micro-emitters upside-down stands complementary accessories.
7. Sprinklers and midi-sprinklers.
8. Sprinklers stands complementary accessories.
9. Micro-tubes and tubes, complementary accessories.
10. Tools.

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