Freeze Protection of Small Fruit Crops - Workshop for Cooperative Extension Agents

Active Frost, Frost/Freeze &Freeze Control Strategies In Strawberry Plasticulture Using Sprinkler Irrigation

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Introduction

Frost and freeze damage to unprotected strawberry buds and flowers can significantly reduce marketable yields and grower profits. Without climate modification techniques (primarily overhead sprinkler irrigation and row covers), the value of a strawberry plasticulture crop in North Carolina, South Carolina, Georgia, Virginia, and Tennessee can been reduced by 1/3rd or more by a series of cold events that typically occur in these southeastern states in late winter and early spring. In this slide presentation I will mainly focus on using overhead irrigation for cold protection, but in another paper included in this notebook, *Using Row Covers in Georgia and South Carolina,* I discuss how during certain weather events row covers may actually be a better alternative to sprinkler irrigation. Further, while overhead irrigation can be highly effective in frost and frost/freeze conditions, it can actually damage the crop when used in an advective freeze without the additional use of a row cover in conjunction with sprinkling.

It makes little sense to invest in an expensive overhead sprinkler irrigation system for cold protection in strawberry, and then not know how to use it! But, knowing how to protect your strawberry plants from cold injury using sprinkler irrigation is not always straightforward, especially when faced with more severe wind conditions and/or low dew point temperatures. So let's begin with a careful review of the several kinds of cold weather events we may experience in the Southeast during late winter and early spring, and in this discussion I will identify the "limits" of overhead sprinkling under high wind conditions.

Slide 1. ***Importance of winds***. A *freeze warning* issued by the NWS tells the strawberry grower that winds will be too high to allow successful use of any cold protection systems, except "perhaps" the use of overhead irrigation in conjunction with sprinkling (more on that later). On the other hand, a *frost/freeze* warning may imply "that a grower can likely provide successful

Recommendations given in this presentation to the Agents participating in *Freeze Protection of Small Fruits* training of the SRSFC on January 4, 2007, are based on experiences accumulated by the author at Central Crops Research Station, Clayton, NC, and conditions in other locations in the Southern Region may differ significantly from Clayton. The author's purpose in this talk is to share his personal frost protection experiences with agents in the hope that they can better advise local strawberry plasticulture growers in dealing with complex frost and frost/freeze protection scenarios and events. This presentation has not undergone departmental review, and the author requests that it not be reproduced or used in other publications. Please contact: Barclay_poling@ncsu.edu to receive a reviewed slide script.

protection" (Perry, 1998), ***provided*** that the strawberry operation is equipped with a well designed overhead sprinkling system. The effectiveness of over-vine sprinkling under *frost/freeze* conditions is largely dependent on how well the system is engineered. In a poorly engineered system, winds of even 5 to 6 mph can limit the success of irrigation for *frost/freeze* protection. Overhead sprinkling can be highly successful in radiational frost conditions (see next slide).[1]

Table. 1 Definition of frost/freeze warnings issued by National Weather Service.

Warning	Wind Speed (miles per hour)	Air temperature (°F)
Frost	Below 10 [z]	Above 32 [y]
Frost/freeze	Below 10	Below 32
Freeze	Above 10	Below 32

[z] There can be possible confusion associated with the NWS scheme of issuing a "Frost Warning," for temperatures *above* 32 F. But this is simply a *warning* of a possible frost event, and the reader should not interpret this to mean that a radiation frost event has temperatures above 32 F near the surface (e.g. in the vineyard mesoclimate). In fact, Perry (2001) defines a *radiation frost* as having temperatures near the surface *below freezing* (32 F).

[1] **Terminology confusion**. While people use the terms *frost* and *freeze* interchangeably, they technically refer to two different weather events. The term *freeze* is normally used to describe an invasion of a large, very cold air mass from Arctic or Canadian regions. A *frost* is a localized type of cold event, and these events occur on nights with calm winds and clear sky conditions. In frost events, heat that is being lost by the plant to the atmosphere is through a radiative cooling energy process and thus the name *radiation frost.* In *freezes*, the primary energy (heat) transfer mechanism is wind, or advection, and thus the name *advective freeze.* I do not employ the term *radiation freeze* in reference to frost events. The term *radiation frost* better describes a cold event in which *radiative* heat losses (not advective) are the dominant characteristic. Of course, limited advective (wind) heat losses can be associated with *radiation frost* events. And, as Perry (2001) defines *radiation frosts* as having "calm winds, but less than 5 mph and temperatures near the surface *below freezing* (< 32°F). A *frost/freeze* combines the characteristics of both a *freeze* and *radiational frost.* Understanding the key differences between *freezes, frost/freezes* and two types of *frost* events (black frost and hoar frost), is extremely important in strawberry plasticulture cold protection management.

Slide 2. ***Radiational frosts.*** Radiational frosts are caused by rapid radiational loss of heat. Radiation is electromagnetic energy transfer, and a good example is sunlight. During the day, the sun's radiant energy warms the soil and other *solid objects*, like strawberry plants. At night, the situation reverses. There is no incoming heat to warm the soil and crops. They continue to lose heat through *radiation and conduction* until they are cooler than the surrounding air (Perry, 2001). Radiative heat loss from plants at night will be promoted by clear skies (no cloud cover present), and still, or very calm winds.

Slide 3. ***Frost protection with sprinkler irrigation.*** Active frost protection with overhead sprinkler irrigation is highly effective under radiational frost conditions where temperatures near the surface are below freezing and winds are relatively calm, as shown in Table 2.

Table 2. Protection Effectiveness by Cold Event, Flower Stage, and Control Method.

Weather Event	**Flower Stage**	**Row Cover Alone**	**Sprinkling Alone**
Windborne freeze	Emerged flower bud	Good to Excellent[1]	Not recommended
	Open blossom	Fair	Not recommended
Frost/freeze	Emerged flower bud	Excellent	Excellent
	Open blossom	Fair	Excellent
Frost	Open blossom	Good	**Excellent**
	Popcorn	Good	**Excellent**

[1] The "protection effectiveness" of row covers alone will depend on cover weight, minimum temperature, and humidity.

Slide 4. ***Let's briefly summarize the information presented up until this point.*** Active cold protection with overhead sprinkler irrigation will work very successfully under radiation frost conditions, and can also be effective in frost/freeze conditions, provided the system is well engineered. Under the high wind conditions of a freeze, overhead sprinkler irrigation systems are not recommended (Table 2), except when used in conjunction with row covers.

Slide 5. ***Knowing how to properly use your sprinkler system.*** I said earlier that it makes little sense to invest in an expensive overhead sprinkler irrigation system for cold protection in strawberry, and then not know how to use it! In this next section of my presentation I will discuss in detail how to use sprinkler irrigation in each of these types of conditions:

- Radiational frosts
  - Black frost
  - Hoar (white) frost
- Frost/freezes
- Freezes (in conjunction with row covers)

Slide 6. ***Avoiding common mistakes in using sprinkler irrigation for radiational frosts.*** When speaking with growers around the Southeast, I have found that many are unfamiliar with what are called *black frosts.* Few or no ice crystals form on plant surfaces in a black frost, and thus the name! Essentially, the lower atmosphere is *too dry* for ice crystal formation, such as you do get when the lower atmosphere is *moist.* When the lower atmosphere is more humid, a *hoar frost* (white frost) can occur (provided that winds are relatively still and skies are clear). Either of these types of frosts can be injurious to strawberry flower parts. However, *black frosts* are always *killing frosts,* whereas a hoar frost may or may not be injurious! It's somewhat complicated, but in the interest of time, I am not going to go into the involved explanation as to how a hoar frost may not be damaging. **The problem is that many times hoar frosts are injurious. So, I wish to clearly communicate to each of you that in a hoar frost condition, it is important to be *proactive* in starting irrigation up at the first appearance of frost (ice crystals) on strawberry leaves.**

Table 3. Characteristics of the Two Types of Radiational Frosts[z]

Hoar (White) Frost	**Black Frost (sometimes called a dry freeze)**
Calm winds	Calm winds
Clear skies	Clear skies
Temperature drop is gradual through the night due to high relative humidity	Temperature drop can be rapid after sunset (more than 2 F per hour) due to relatively dry atmosphere
Dew point may be the above the critical temperature for buds and shoots, and hoar frost is not necessarily injurious to plant tissues	Relatively dry air (low dew point); dew point temperature is below critical temperature of sensitive plant tissues, and black frosts are always *killing frosts*

Ice crystals form on surface of solid object from water vapor (not dew)	Development of ice crystals depends on dew point, or frost point of air
Frost formation may trigger ice nucleation and possibly plant freezing	Plant freeze injury may occur in absence of ice crystals forming on plant surface
Initiate frost protection at 1st sign ice crystal formation on plant tissues	Frost protection is more complicated as plant tissue temperatures may be several degrees below air temperature under low humidity atmospheric conditions

[z] Perry (2001) defines a *radiation frost* as having temperatures near the surface below freezing (32 F), and winds of less than 5 mph.

Slide 7. ***A typical hoar frost scenario***. A potential *hoar frost scenario* in North Carolina would be:

1) air temperature forecast in the mid-to-low 30s,
2) dew-point temperature forecast in the low to mid-30s
3) calm wind forecast of less than 3 mph
4) clear to mostly clear skies (no cloud cover)

Slide 8. ***Importance of dew point temperature in predicting a hoar frost.*** Dew point (DP) temperatures are an excellent "indicator" of whether the lower atmosphere is going to be moist enough for ice crystals to form on the surface of plant tissues. And, when the forecast is for DP temperatures in the upper 20's and low 30's (indicating that the lower atmosphere is "moist"), the frost protection strategy for sprinkler irrigation is to pay very close attention to the start of ice crystal formation on plant tissues – this is your most important "cue" as to when frost protection must be started – *the goal is to prevent ice crystals from forming.*

Slide 9. ***Natural factors that will counteract a hoar frost.*** Although DP temperature is an excellent indicator of the potential for a hoar frost, you should also be aware of other important conditions, including calm winds and clear skies. Natural factors that will keep ice crystals from forming include winds greater than 5 miles per hour, cloud cover, and potentially drier soil conditions (Table 4). Thus, in cloudy, breezy weather, frost will not occur and observed low temperatures will likely be very close to forecast values. But under clear calm conditions with DP temperatures in the upper 20s to lower 30s, there is potential for heavy frost (and blossom injury).

Table 4. Natural Factors That Favor as Well as Counteract Ice Crystal Formation	
Favor	**Counteract**
Calm winds	Winds > 5 mph (slows radiative cooling of solid objects)
Clear skies	Cloud covers – act as a blanket; the thicker the cloud cover the slower the cooling rate
Surface air temp. at 32 F, or below	Surface air temp. above freezing
Dew point temp. in upper 20's and lower 30's	Dew point temp. in mid 20's and lower (atmosphere is too dry)
Soils containing abundant water	Drier soil conditions

Slide 10. ***Dry atmosphere conditions and black frost.*** As previously stated, few or no ice crystals form on plant surfaces in a black frost. And, by the time you see crystals on blades of grass, your pickup truck hood, or tender strawberry blossoms, the damage has been done. Temperatrues will already dipped below the critical temperature point(s) of a strawberry blossom (28-30 F—some range in critical temperatures for open blossom stage is more realistic than a single set temperature), and irreversible crop injury will be the outcome. You cannot wait until you see "ice crystals" if the DP temperature is low. If the DP is in the mid-20s (relatively low), for example, you will not be able to see (or feel) any ice crystals forming on the plant surface until the air temperature drops into the mid-20s – this is the frost point (temperature to which the air must be cooled to cause atmospheric moisture to change from gas to solid).

Slide 11. ***Let's summarize why DP temperature is so important.*** Dew point temperature is a good way to describe the humidity or amount of water vapor in the air, and it has great practical value to strawberry growers because it will indicate whether frost can be expected to form near the freezing point (32° F), or not. When the dew point is below 32° F, it is sometimes called the *frost point* because frost can form when the temperature is below freezing. Basically, the drier the air, the great the potential for frost to form at temperatures below 32°F. **From a frost protection management perspective, you cannot wait until you see frost if the DP is low.** It is very important to know the dew point in strawberry frost protection from the perspective that it will tell you whether you will likely experience a hoar frost or black frost. In other words, it is not satisfactory to only take into account minimum temperature information in developing your radiation frost protection strategy – it is far better to look at both air temperature and DP temperature. Other presenters in this workshop have discussed how to obtain DP temperatures for your area, or to determine the DP temperature yourself by using a sling psychrometer and using psychrometric tables for obtaining dew point.

Slide 12. ***Get advance weather forecast products to plan your control strategy*** . As stated in the milestone extension bulletin, *Frost and Frost Control in Washington Orchards* (J.K. Ballard, 1981), the grower, "… must know the kind of frost confronting him each time the frost alarm rings." But, even before the frost alarm rings, an advance weather forecast is an invaluable tool that allows the modern day vineyard producer to make an educated guess about what can potentially happen several days, or more, before the cold event occurs. Control options and strategies can be further revised as more information becomes known about the event in 48 hour and 24 hour updates. Weather forecasts for a specific strawberry farm should provide the following information:

- When a cold event is coming.
- How cold it will get (minimum air temperature at the weather shelter level of 5 feet).
- How long the cold may last (duration).
- Wind speeds and direction.
- Humidity – whether it will be low or high. (Dew point is the best way to describe the amount of water vapor in the air.)

Commercial providers of specialized weather forecasts are increasing, and a number of these services are Web-based and offer a variety of products, discussed by others in the workshop.

Slide 13. **Wind forecasts and speeds are an important "issue" in sprinkler irrigation.** Unfortunately, the current methods for predicting wind speeds coupled with widely varying terrain for mountain zones of North Carolina, for example, greatly limit the capability of various weather forecast services to provide meaningful wind forecast products for this region of the state. Nonetheless, it is important for you to do the best you can to obtain as reliable information on likely wind speeds, **as sprinkling rates for overhead irrigation are determined in part by wind speed (Table 5).**

Table 5. Required Irrigation Rates (in/hr) To Maintain a Critical Temperature of 28° F and Relative Humidity of 70%

	Wind Speed			
Min. temp(^{O}F)	0-1 mph	2-4 mph	5-8 mph	9-14 mph
27	0.10	0.11	0.14	0.16
26	0.10	0.13	0.16	0.17
25	0.10	0.14	0.18	0.21
22	0.10	0.18	0.24	0.29
20	0.11	0.21	0.28	0.34
18	0.12	0.23	0.31	0.38
15	0.13	0.26	0.35	0.43

Slide 14. ***Using temperature and wind speed forecasts to determine precipitation rate.*** Use the minimum temperature forecast and the wind speed forecast to identify the maximum sprinkling (precipitation) rate needed with 70 percent relative humidity (see Table 5). Tables that indicate temperature times wind precipitation for higher and lower humidity levels can be also be obtained from your state climatology office. Lower rates of sprinkler irrigation can be used on nights with relatively calm winds (Table 5). Anything that promotes evaporation, however, such as low humidity and high wind speed, will also promote overall blossom cooling, and higher precipitation rates are thus required to offset what are called "evaporative cooling" heat losses.

Slide 15. ***Important principles of sprinkler irrigation.*** The use of overhead sprinkler irrigation for frost and frost/freeze protection relies on two key principles: *heat of fusion* and *heat of vaporization.* As water freezes, heat is released by the freezing process (heat of fusion). The amount of heat generated when water freezes is 1,200 British thermal units (btu) per gallon or 80 calories per gram of water frozen. This heat keeps plant temperatures safely at 31.5 to 32 F when air temperatures are colder. The ice and water mixture is at about 30.9 °F. As long as an *adequate layer of freezing water* covers the strawberry buds and blossoms, the temperature will stay above the critical damaging temperature (around 28-30° F for open blossom). With very low air temperatures, greater rates of water application are required for adequate protection. Also, the presence of wind while sprinkling over the vines can lead to serious problems if sprinkling rates are inadequate to offset evaporative cooling heat losses. You risk more extensive crop losses due to the evaporative cooling effects if sprinkling is inadequate. Since the heat taken up by evaporation at 32 F is about 7.5 times as much as the heat released by freezing, at least 7.5 times as much water must freeze as is evaporated. Thus, relatively high sprinkling rates are required under windy compared to calm wind conditions (see Table 5), and this is needed to both supply heat to warm the plants as well as to satisfy heat losses through evaporation. Keep in mind that under cold and conditions that evaporation is happening all the time from the liquid and frozen water, and if the system should fail at anytime during the night, it goes *immediately* from a heating system to a very good refrigeration system, and damage can be much worse than if no protection has been used at all!

Slide 16. **Avoiding the "cold jolt".** Furthermore, there may be what is called an "evaporative dip," or "cold jolt," due to evaporative cooling of the sprinkler drops when the system is first turned on. This 15 or 20 minute dip can push temperatures of the strawberry plant tissues below their critical point and cause serious cold injury at the outset of the sprinkling operation. Under conditions favoring evaporative cooling (winds and low humidity), it is very important to **turn-on the sprinklers** on the basis of **wet bulb temperatures**, and **not ambient temperatures**.

Slide 17. **Using wet bulb temperatures in sprinkler irrigation for cold protection.** Knowing wet bulb temperature is especially important to growers who use over-vine sprinkler irrigation for frost/freeze protection of strawberries. **Growers need to know the wet bulb temperature to determine when to turn the irrigation system on and off.** Wet bulb temperature is a measurement of the evaporative cooling power of the air and can be measured using a sling psychrometer, and instrument comprised of two thermometers. The wet bulb temperature has a gauze wick attached to the bulb end; and to measure wet bulb temperature, the gauze wick is immersed in water, and the instrument is swung in a circular motion for a few minutes. The lower the moisture in the air, the lower the temperature of the bulb will drop (the amount of temperature drop is proportional to the rate of evaporation). Except under conditions in which the air is saturated with moisture, the wet bulb temperature is normally lower than the air temperature but higher than the dew point temperature. For example, when the air temp is 33° F, and the wet-bulb is 30° F, the dew point is 25° F. By waiting to turn on the irrigation system until the wet bulb is below 30 F, you are running a significant risk of blossom injury due to the cold jolt phenomenon.

Slide 18. ***What if I don't have wet bulb temperatures?*** Without access to wet bulb temperature information or access to a digital thermometer and thermocouples for taking direct blossom temperatures, you can use dew point temperature information to give you a reasonably good idea as to when to turn the sprinklers on for low humidity nights. If the dew point is in the low- to mid-20s and air temperatures are dropping at an average of dropping at 2°F per hour, sprinkling should begin at around 34°F. With dew points in the upper teens and a cooling rate of around 3°F per hour, a safe turn-on temperature will be around 35°F. It is far better to waste 30 minutes or so of irrigating early in the evening than to risk damaging the strawberry blossoms by "waiting too long" to start-up. Under low wind speeds (less than 2 mph) and/or no winds, along with relatively high DP temperatures (upper 20s and low 30s), *start frost protection at the first sign of ice crystals forming on the plant surfaces (this is a hoar frost condition).* On occasion, dew point temperatures in the low teens and single digits can occur when very cold and dry air masses from Canada move into the region. In these situations, temperature drops of as much as 6°F per hour can occur. Under such conditions, it is vital to provide an even greater safety margin, and irrigating needs to start at 37°F to 38°F (this can mean starting irrigation as early as 30 minutes *before* sunset).

Slide 19. ***Alternative technique for wet bulb estimation.*** A quick technique that many forecasters use to determine the wet-bulb temperature is called the "1/3 rule". The technique is to first find the dewpoint depression (temperature minus dewpoint). Then take this number and divide by 3. Subtract this number from the temperature. You now have an approximation for the wet-bulb temperature. Here is an example: suppose the temperature is 42 degrees Fahrenheit with a dewpoint of 15 degrees Fahrenheit. The dewpoint depression is 42 - 15 = 27. Now divide 27 by 3 = 9. Now subtract 9 from the original temperature of 42. 42 - 9 = 33. If the temperature was 42 with a dewpoint of 15 and it started raining (or strawberry overhead irrigation was initiated), the temperature and dewpoint would wet-bulb out to a chilly 33 degrees Fahrenheit. As dewpoint depression or temperature increase, the evaporational potential increases. This technique does not give the exact wet bulb temperature but it does give a pretty close approximation. Warmer air will cool at a greater rate than colder air since more water vapor can evaporate into warm air. Evaporation is a cooling process, therefore the more evaporation the more cooling. For temperatures between 30 and 60 degrees F, the 1/3 rule works quite well.

Slide 20. **Once sprinkling starts** and an ice coat has built up, the system must operate continuously through the night until the strawberry plants are free of ice the next morning, or at least until the wet-bulb temperature of 32° F has been reached. The operator should be especially cautious about stopping the application of water during the night if the temperature rises because of a light breeze or a few clouds. Once the breeze falls or the clouds disappear the temperature will probably drop rapidly again. With sprinkler irrigation for frost protection in strawberries, the system must be designed for worst-case conditions, and there are several excellent irrigation suppliers in North Carolina, South Carolina and Virginia who can design a vineyard sprinkler system to provide protection down to a target temperature of 16 to 18° F. Water should slowly but continuously drip from the plants when the sprinkling system is working properly. The application rate is not sufficient if the ice has a milky color (from occlusion) – it should be clear at all times. Large amounts of water are required for strawberry black frost and frost/freeze protection, and growers are advised to size their ponds to provide for 3 continuous nights of protection at 10 hours per night. For example, 5.7 acre inches of water (27,152 gallons equal one acre inch) would be needed for sprinkling at the rate of 0.19 inch/hr (for control down to 22° F), for 10 continuous hours each night over 3 nights. Or, 1.9 inch/night (10 hr x 0.19 inch) x 3 nights = 5.7 acre inches. An irrigation pond would need to hold about 155,000 gallons of water for each acre of vineyard production under these conditions (5.7 inch x 27,152 gal per acre inch = 154,766 gallons).

Slide 21. **Shut-down of irrigation system** – operate continuously after sun-up until you can see free water running between the ice and the strawberry blossoms, or until ice slides easily from the strawberry plant parts. This means that the air temperature is above 33 F in the outside area. It is not necessary to run until all the ice has melted after the warm sunlight "takes over". But, if the morning should turn cloudy after sunrise and/or if there are chilly winds, CONTINUE TO RUN THE IRRIGATION UNTIL THE **WET BULB** TEMPERATURE IS **ABOVE 32^{O} F** IN THE COLDEST PORTION OF THE OF THE STRAWBERRY PLANTING.

Slide 22. **Freeze conditions.** Perhaps the most challenging situation that can arise is when you have numerous open blossoms per plant, and winds exceed 14 mph. Under these circumstances, it may be best to irrigate on top of the row covers in an attempt to save the open blossoms. Experience with this technique is still limited, but if you are able to keep your irrigation system functioning all through the night and early morning, there is a good potential of saving many of the open blossoms, most of the popcorn blossoms, and virtually all of the emerged flower buds. Again, you must strive to keep your irrigation system functioning all through the night and early morning. Do not just form the "ice igloo" and go to bed.

Slide 23. **Use a thermocouple temperature measuring instrument.** Events can change quickly during the hours leading up to a weather event. Cloud cover can move in quickly. On the eve of sprinkling for a frost/freeze, the forecast may not match what is actually happening in your field at the plant canopy level. One of the simplest and most reliable methods for monitoring the "net effect" of changes in air temperature, humidity, and wind speed, is to check the *actual temperature of the blossom* with a thermocouple temperature measuring device that is small enough to be inserted into buds or blossoms. Thermocouple blossom temperatures are reliable for guiding decisions on when to start irrigation and whether irrigation is sufficient (if blossom temperatures drop below 30°F, the sprinkling rate must be increased). Knowing the blossom temperature removes the guesswork from determining when it is safe to turn off the irrigation system in the morning. Sometimes this is a very difficult decision to make, especially when dew point temperatures are very low and winds pick up in early morning. As you become familiar with the use of a thermocouple to monitor strawberry blossom temperatures, you will notice that blossom temperatures are frequently 1 to 2° F below the canopy air temperature as measured with a liquid-in-glass thermometer (in other words, when a blossom temperature reading is 31°F, the air temperature in the plant canopy may be 32 or 33°F).

Slide 24. **Calibrate the instrument used for temperature measurement.** Regardless of the type of instrument used, the instrument must be checked and adjusted if necessary to ensure it is measuring temperatures correctly. A simple way to make sure the device is reading correctly is to place the sensor into water with crushed ice, gently stirred. Make sure the sensor or thermometer base is submerged in the water. The temperature should read within one degree of 32°F within 10 to 15 minutes.

Slide 25. ***Final pointer - check out your overhead irrigation system*** at least two weeks before it may be needed for strawberry frost/freeze or frost protection to allow time for making any needed adjustments and repairs in the lines and pumps. This is also the time to evaluate certain performance characteristics of your sprinkler system:

- Overlap of sprinkler patterns. (A 40-foot by 40-foot sprinkler spacing will provide greater uniformity of application under windy conditions than traditional 60-foot by 60-foot settings.)
- Sprinkler rotation speed. (You need at least one revolution per minute.)
- Sprinkler discharge rates. (Make sure that they are within the manufacturer's specified ranges. By making test runs with your system, you can verify actual sprinkler discharge rates for different sprinkler nozzles and pressures.)

References

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