Irrigation for Apple Orchards

Apples benefit from irrigation. Vegetative tree growth and fruit size respond to soil water applications. Fruit color, soluble solids, firmness and physiological disorders can be influenced by over-tree sprinkler irrigation to reduce heat stress when temperatures are high. The same over-tree sprinkler irrigation system can be used, under most conditions, for protection against spring frost and frost/freeze injury. All of the above uses of irrigation have been evaluated and are recommended for use in North Carolina apple orchards.

Soil Moisture Maintenance

Benefits
Any of several methods of irrigation—trickle, hand-movable aluminum pipe, self-propelled traveler, solid set or permanent systems—can be used for supplying water to the root zone of apple trees. Research in North Carolina has demonstrated that maintaining good soil moisture promotes improved vegetative growth, particularly on young trees, and contributes to improved fruit growth. Also, flower buds of apples are developed in the summer and fall, and maintaining soil moisture encourages an adequate number of strong flower buds the following spring.

Water Requirements
The quantity of water required for maintaining adequate soil moisture is influenced by many factors such as tree spacing, crop load, soil type, slope, temperature, wind and humidity. It has been estimated that a mature tree with a full fruit load will use 50 gallons of water on a hot summer day. For 100 trees per acre over a 7-day period, this equals 35,000 gallons. This figure does not include water used by orchard floor vegetation or lost to surface evaporation. A good rule of thumb is that an orchard needs a minimum of 1 inch of water per acre per week, or 27,154 gallons. With 75 percent irrigation efficiency, about 36,000 gallons of total irrigation will be required to provide this amount.

Trickle Irrigation

Advantages and Disadvantages. Irrigation systems limited to soil moisture maintenance are the least expensive type of apple orchard irrigation. Where water supply is limited, trickle or drip irrigation is an efficient low pressure, low volume method of applying water to the root zone of each tree. Water is not wasted in alleys between tree rows or between trees in the row.

Trickle irrigation normally requires only 50 to 75 percent as much water as a sprinkler irrigation system. Initial costs per acre are comparable to portable sprinkler irrigation systems used only for soil moisture maintenance but operating costs of the trickle system are lower than operating costs of the sprinkler system because it operates at a lower pressure and requires less water.

Trickle irrigation for supplying soil moisture is a viable option where water supply is limited or the grower is unable or unwilling to make the greater investment for over-tree sprinkler irrigation. However, the grower must realize that trickle or drip irrigation cannot provide summer evaporative cooling or spring frost and frost/freeze protection.

System Design. Design of a trickle system can be somewhat complicated. Since the system is operated at low pressures, small variations in elevation can significantly affect emitter discharge. Careful selection of pipe sizes and location of pressure-regulating valves are important. Trickle emitters should be placed on at least two sides of mature bearing trees and four emitters are recommended, especially on sandy loam soils. Emitters should be placed half way between the trunk and branch drip line.

Most trickle irrigation emitters discharge 1/2, 1 or 2 gal/hr at a prescribed pressure. Small differences in pressure can cause amount of water discharged to fluctuate widely. Pressure-compensating emitters which can hold discharge essentially constant over a wide range of pressures are available at a higher cost.

Trickle irrigation should be operated for a given period of time each day, regardless of the rainfall. The orchard can be divided into two or more irrigation zones with the same pump supplying water to
each zone for a portion of each 24-hour period. Each zone of trickle irrigation will need to be operated for 4 to 12 hours or more per 24-hour period, depending on emitter volume, soil moisture stress and crop load.

Adequate filtration is essential for successful trickle irrigation. Minerals, fine sand, bacteria or algae will plug emitters. Lack of proper filtration will lead either to failure or less-than-satisfactory performance of drip systems.

**Evaporative Cooling**

**Benefits**

Water plays a major role in regulating the temperature of the foliage and fruit. As the water in the leaves is vaporized and lost from the plant by transpiration, the plant is cooled. Often during the day with low humidity, high temperatures, and intense sunlight, water is lost to transpiration faster than the root system can replace it from the soil. When these conditions occur during fruit development and harvest, water may be withdrawn from the fruit to supply the plant. This can result in smaller fruit, delayed maturity and reduced fruit quality.

Evaporative cooling (EC) is a method of reducing heat stress on plants by lowering temperatures, raising relative humidity, and reducing transpirational water losses. The EC technique involves the application of a relatively low volume of water over the tree canopy during periods of environmental stress. EC reduces high fruit temperature, high rates of water loss from the tree, and high respiration which is caused by high temperature, low humidity and wind.

Average fruit temperatures are generally reduced by 8° to 12°F; however, temperatures of sun-exposed red apples can be reduced by as much as 25°F. EC irrigation improves fruit quality as measured by increased color of red varieties, produces a higher percent of soluble solids, concentrates ripening, advances maturity, and produces larger fruit.

Evaporative cooling complements the use of ethephon and 2,4,5-TP growth regulator use on apples, aiding the stimulation of red color and sugar content. Adequate soil moisture is a prerequisite for good ethephon response. See NCAES bulletin *Growth Regulator Usage in North Carolina Apple Production*. No disease or related problems have occurred with the use of EC irrigation on apples.

**Methods and Equipment**

**Rates and Placement.** Application rates of 0.08 to 0.12 in/hr are satisfactory for EC irrigation. However, the rates of 0.15 to 0.18 in/hr used for frost and freeze protection are more efficient. A greater volume of water wets more of the plant in a shorter time. Evaporation can take place from a larger surface area and cool the plant more quickly.

Evaporative cooling irrigation requires a solid set or permanent irrigation system. The system can be operated with the entire system cycling according to temperature demands, or it may be operated in zones by sequencing the laterals in a section of the orchard. Sequencing can be accomplished by irrigating a block of trees in one area or by operating only certain lateral lines such as 1,4,7 and 10 at one time and then operating another group of laterals. Spacing lateral lines in every other row of trees versus every third row gives more uniform water application and evaporative cooling. Sprinklers must operate frequently enough to keep the fruit temperature below damaging level. The system operation must be automated, and an electric pump is essential for quick, intermittent operation.

**Timing.** Timing of intermittent EC irrigation depends on the intensity of the environmental stress. Duration and frequency of irrigation are determined by water application rate and atmospheric conditions such as temperature, wind, relative humidity, and cloud cover. The best sensor of these environmental conditions is the fruit itself. It is recommended that the EC irrigation system operation be controlled by the temperature of sun-exposed fruit. A 5°F change in fruit temperature, as measured by a special thermistor (Fig. 1), has been used for cycling the EC irrigation. The system is generally cycled on at a fruit temperature of 98 to 97°F and cycled off when fruit has cooled 5°F.

**Relative Humidity.** EC irrigation is most effective at lower relative humidities since the potential for evaporation is greater. Relative humidity (RH) is determined by comparing the temperature of a wet bulb thermometer with the temperature of a dry bulb thermometer. RH is low and the potential for evaporative cooling is high when there is a large dif-

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*Fig. 1 A special thermistor such as the one shown can be used to cycle evaporative cooling irrigation. The thermistor measures each 5°F change in the temperature of an exposed apple fruit.*
ference between wet bulb and dry bulb temperature. The wet bulb temperature is the minimum cooling attainable with EC irrigation, i.e., the temperature at which the air becomes saturated. On extremely humid days, the wet bulb temperature may rise above the "off" temperature setting on the fruit temperature controller. If this happens, the system will operate continuously since cooling cannot occur when the air is saturated. Continuous operation will normally result in excessive soil moisture.

Frost/Freeze Protection

General Principles

The use of overhead sprinkler irrigation for frost and frost/freeze protection is well established for apples. The ultimate benefit of frost and frost/freeze protection is to prevent the flowers and/or fruit from being killed by temperatures that drop below the critical level. This critical temperature varies with stage of flower and fruit development and is somewhat variable and hard to predict because of preconditioning weather conditions. Other less obvious, but equally important, benefits of frost and frost/freeze protection include prevention of misshapen fruits, prevention of rough fruit finish, and improved fruit size. Frost can cause rough fruit finish, if it occurs after fruit has been formed.

Several factors influence how much injury is caused by low temperatures. These are: (1) Stage of development. If the frost or freeze is preceded by several days of warm weather, the plant will be growing vigorously and damage will be greater than if the freeze has been preceded by several days of cool weather. Buds in tight clusters will not be damaged as easily as more open buds. (2) Severity and duration of the frost/freeze. The colder the temperature and the longer the freezing period, the more severe the damage. (3) Wind speed and cloud cover. Heavy cloud cover will prevent the temperature from dropping as low as would be expected under a clear sky. A 4 mph wind will prevent damage from frost as long as the air temperature remains above 32°F.

The term frost denotes calm conditions with air temperatures above freezing which result in frost crystal formation on plants. The term frost/freeze denotes calm winds and temperatures below freezing which result in frost formation on plants. The term freeze is used to describe conditions with wind speeds above 10 mph and temperatures below freezing. A freeze is generally considered not protectable with the use of over-tree irrigation at the recommended application rate.

Latent heat of fusion is the principle that makes frost and frost/freeze protection by sprinkler irrigation effective. When 1 gram of water at 32°F is changed to 1 gram of ice at 32°F, 80 calories of heat are generated. Freezing water warms the plant's surface and keeps it at or near 32°F even though the temperature of the surrounding air may be somewhat lower. It is most important to keep liquid water on the plant at all times to counteract heat loss due to radiant cooling of plant parts. Sprinklers that have a more rapid rotation than normally used for irrigation (1 rotation per minute) are helpful in maintaining a constant layer of freezing water.

As the air temperature decreases below freezing, the volume of water required to give protection must be increased. When insufficient water is being applied, ice formation takes place very rapidly with the inclusion of air bubbles and the ice will have a milky white appearance. Clear ice indicates good protection. Sprinkler irrigation should continue throughout the cold period until the air temperature is above 32°F and the ice has begun to melt rapidly and is loose on the plant parts. Frost and frost/freeze protection irrigation must be either the solid set or permanent type and capable of continuous operation over the entire crop for the duration of freezing weather conditions.

Factors Influencing Protection

Application Rate and Wind. The maximum protection achievable depends on the designed water application rate. The actual amount of protection obtained depends on the rate of water applied plus wind speed and RH. The major problem with sprinkler irrigation for frost/freeze protection is its limited protection under windy conditions. The leaching of plant nutrients when the system has to be operated for long periods and the need for good tree structure and pruning to carry the ice load must also be considered.

The difficulty with wind is demonstrated by data from Florida (Table 1). These data suggest that for the same temperature, application rates required for 5 mph winds are three to four times greater than those for no wind. Once the system is started on a given night, it must be operated until the air temperature goes above 32°F and ice is loose on the foliage. The grower must often make a decision about whether to irrigate or not. When continuous wind is forecast, the decision is easy—the system should not be started. Do not attempt sprinkler irrigation if wind speed is above or predicted to be above 5 mph, especially if low to mid twenties temperatures are forecast.

Temperature. To prevent frost and frost/freeze damage, the fruit must be kept above the critical temperatures at which sap freezes. Applying the correct amount of water to leaves, buds, and fruit will prevent tissue temperature from dropping below 30 to 31°F. When sprinklers are first turned on, there is a rapid temperature decrease of about 2°F. To prevent damage, the system should be started at 34°F.

In apple orchards, after fruit set has occurred, the start-up temperature of the irrigation system should be raised from 34° to 37°F. This will allow system operation at temperatures at which frost formation could occur on fruit surface and cause rough finish.
Table 1. Application rate in inches/hour recommended for cold protection under different wind and temperature conditions.

<table>
<thead>
<tr>
<th>Temperature Expected</th>
<th>Wind Speed in M.P.H.</th>
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<tbody>
<tr>
<td></td>
<td>0 to 1</td>
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<tr>
<td>27°F</td>
<td>0.10</td>
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<tr>
<td>26°F</td>
<td>0.10</td>
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<tr>
<td>24°F</td>
<td>0.10</td>
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<tr>
<td>22°F</td>
<td>0.12</td>
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<tr>
<td>20°F</td>
<td>0.16</td>
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<tr>
<td>18°F</td>
<td>0.20</td>
</tr>
<tr>
<td>15°F</td>
<td>0.26</td>
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</tbody>
</table>

Temperatures near freezing are important. Where these temperatures are measured is also important. A thermometer should be placed at the level of the lowest limbs in a low spot in the field and exposed to the open sky. If a source of power is available, a thermostat in the field can control a warning bell that will ring when the temperature in the field drops to 36 to 38°F (Fig. 2). The irrigation system can be automated by connecting the thermostat into the power circuit of the electric motor. It is very important that the thermometer or thermostat be calibrated to ensure that it gives a true reading. Any thermometer or thermostat can be accurately calibrated at 32°F by immersing the remote bulb or entire thermostat sensing area into a pail of crushed ice and water and stirring constantly for several minutes. Stirring will make the temperature of the water-ice mixture and the thermostat uniform.

Sprinkler Irrigation Systems

Sprinkler Placement and Design. Where conventional sprinkler irrigation equipment is used for frost and frost/freeze protection, single nozzle sprinklers are required to provide low application rates of 0.16 to 0.18 in/hr. Sprinkler spacing of 50 to 65 percent of effective diameter is normally recommended to provide uniform water application.

Most growers who install sprinkler systems will use these systems for irrigation as well as frost and frost/freeze protection and will not change sprinklers or sprinkler nozzles. For these multipurpose systems, sprinkler spacing should not exceed 60 percent of effective diameter. There are a number of sprinkler spacings that can be used; however, to obtain the recommended application rate, a spacing greater than 80 ft. X 80 ft. is not feasible and a spacing near 60 ft. X 60 ft. is closer to the acceptable range.

Fig. 2 Install a bell alarm system for frost/freeze warning. A thermostat placed in the field can be wired to trigger the alarm when the air temperature drops below 36 –38°F.
Research conducted in North Carolina on apples has indicated that better protection is obtained when sprinklers are placed in every other row of trees. Where sprinklers are placed in every third row of trees, some damage was noted in extreme conditions.

Some sprinkler manufacturers now offer a specially designed frost and frost/freeze model. It is designed with the tail of the arm removed. On some models the sprinkler arm spring is also shielded. Under severe icing conditions, the sprinkler arm and arm spring can ice over and the sprinkler will stop rotating. This special rotary impact sprinkler corrects this problem. The rotary impact sprinkler also has a faster rotation speed, but sprinkler diameter is smaller for the same flow rate as conventional sprinklers, making it less adapted for multipurpose use.

**Precipitation Rates.** Table 2 shows precipitation rates for selected capacities and spacings. To compute the precipitation rates for a spacing and sprinkler gallonage combination, use the following equation:

\[
\text{Precipitation rate (inches/hour)} = \frac{96.3 \times \text{Sprinkler GPM}}{\text{Sprinkler Spacing} \times \text{Lateral Spacing}}
\]

**Example:**

- Sprinkler Spacing = 60 feet
- Lateral Spacing = 72 feet
- Sprinkler GPM = 6.20 gpm

\[
\text{Precipitation rate (inches/hour)} = \frac{96.3 \times 6.20}{60 \times 72} = 0.138 \text{ inch/hour}
\]

For apples that have a very large foliage canopy, a precipitation rate of 0.16 to 0.18 inch per hour, applied over-tree, is recommended. Adequate frost and frost/freeze protection has been reported with under-tree sprinklers but these reports have come mainly from arid areas where less protection is required.

**System Design**

**Design.** Two types of sprinkler plumbing systems are being used—solid-set, above ground aluminum pipe or plastic pipe of polyvinyl chloride (PVC) or polyethylene (PE) and the permanent, below ground pipe system using mainly PVC plastic pipe. Most growers use the above ground system for annual and perennial crops such as strawberries. Permanent systems are more adapted to apple trees that have a long life. Some growers are using aluminum pipe laterals in tree fruits. Generally the initial costs will be about the same as that for materials and installation of a permanent system. A few growers have used above ground PVC and PE plastic pipe lateral lines. This is normally not recommended, but one grower has a system that has operated satisfactorily for at least 7 years. The portability and resale value of the plastic pipe material is not as good as aluminum pipe, but the initial cost is less.

The permanent lateral is normally run down the alley between two rows with sublaterals extending to the tree row. Risers and sprinklers are placed in the tree row. Some type of support is needed for tall risers. Wooden posts are recommended over metal posts. A post that extends 5 feet above the ground

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**Table 2. Precipitation rate in inches/hour for selected nozzle capacity and sprinkler spacing**

<table>
<thead>
<tr>
<th>Sprinkler Spacing (feet)</th>
<th>Nozzle Capacity in Gallons Per Minute</th>
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<tbody>
<tr>
<td></td>
<td>2</td>
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<tr>
<td>30 X 30</td>
<td>.21</td>
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<tr>
<td>30 X 40</td>
<td>.16</td>
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<td>70 X 70</td>
<td>.12</td>
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<tr>
<td>70 X 80</td>
<td>.10</td>
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<tr>
<td>80 X 80</td>
<td>.12</td>
</tr>
</tbody>
</table>

* Insure that sprinkler spacing does not exceed 60% of sprinkler diameter on a square spacing or 67% of sprinkler diameter on a rectangular or triangular spacing for the long side of the rectangle or triangle.
and has a 3-inch top diameter will support a 12-to-17 foot riser. (See Figure 3).

In designing frost and frost/freeze protection systems, standard irrigation design criteria are followed. To provide adequately uniform water application, friction loss in the lateral lines should not exceed 20 percent of recommended sprinkler pressure. Pressures 10 to 15 psi higher than those for soil irrigation are needed to give smaller droplets and faster sprinkler rotation. If sprinklers with greater capacity are to be installed for soil moisture irrigation, be sure that lateral pipe diameter is large enough to carry the increased flow without excess friction loss. The 20 percent friction loss factor should be based on the pressure used for soil irrigation. Figure 4 shows a typical permanent system layout.

Elevation. Elevation should also be considered in the design. For every 2.31 feet of elevation, there is a pressure drop of 1 psi. For frost and frost/freeze protection where the entire system is operating at one time, pressure differential between the sprinkler with the highest pressure and the one with the lowest pressure should not be more than 30 percent (including both elevation and friction loss). This means that sprinklers with the lowest pressure will discharge approximately 15 percent less water than sprinklers with the highest pressure. Where elevation differences are excessive, pressure regulating or flow control valves may be needed. The use of these valves adds to the cost of the system, but a more uniform precipitation rate will be obtained.

Main line friction loss also needs to be calculated. Since multiple laterals are operating from one main line, there will be decreased flow in the main line from the field edge nearest the water source to the field edge farthest from the water source. Main line friction loss, elevation and lateral line friction loss are a portion of the 30 percent allowable pressure differential.

Pump. The pump and power unit must have adequate capacity to provide water for the entire area to be irrigated, at a pressure sufficient to operate the sprinklers at the required pressure. Sprinkler pressure requirements, lateral line friction loss (loss in the longest lateral line only), main line friction loss, elevation difference, pump suction lift, and loss through valves and fittings must all be considered in selecting pump pressure required. The reliability and convenience of electric-motor-driven pumps make them a good choice.

Summary of Frost/Freeze Irrigation

A properly designed and operated sprinkler irrigation system can protect crops against most frost and frost/freeze conditions encountered. Its application has limited to winds below 5 mph.

1. Sprinkler irrigation is being used successfully to protect apples against frost and frost/freeze con-
ditions. Damage can occur under windy conditions or when the system is not started soon enough, does not operate continuously, or is shut down before ice is loose on buds and foliage.

2. Have the system designed by a competent irrigation dealer.

3. Provide good surface water drainage (eliminate low, standing-water areas).

4. Insure that the water source is adequate for a severe season. A system that has given protection for several weeks, and then has no water for the last critical night of the season is very undesirable.

5. Set up the system and test it before the need for use arises.

6. Use a calibrated thermostat or good quality thermometer to measure temperatures. Place it at the lowest spot in the field at the height of the lowest branches. Figure 2 is an example of an alarm system that can be used with a thermostat.

7. Start the system at 34°F before fruit set and 36°F to 38°F after fruit set. Operate it until air temperature outside the area is above 32°F and ice has loosened from the foliage.

8. Use an application rate of 0.16 to 0.18 inch per hour for large-canopy tree crops such as apples.

9. Operate the system continuously. To obtain protection against frost and frost/freeze injury, liquid water must be available to turn to ice. With frost and frost/freeze protection, this is normally not possible when the system is cycled on and off.

10. During irrigation, measure the temperature outside the field, but away from the influence of the sprinklers to determine minimum temperature reached.

11. Check the system frequently during nights of fluctuating temperatures.

12. Operate the sprinklers 10 to 15 psi above the normal operating pressure for irrigation. This gives better breakup and smaller droplets.

13. Install a reliable alarm system. Do not operate the system for several nights with good results and then let a late frost or frost/freeze destroy your crop and all your good efforts.

14. Consult all available weather information, especially for expected wind conditions. Do not run your system until the wind has remained consistently below 5 mph for at least 30 minutes and do not start then if wind is predicted to increase later that night.

15. Frost and frost/freeze damage can be protected against with reliability when wind is below 5 mph and if temperatures do not go below 20°F. At temperatures below 15°F and/or with winds above 5 mph, irrigation for frost/freeze protection is uncertain. For a discussion of other types of frost and frost/freeze protection see NCAES bulletin entitled Frost and Frost/Freeze Protection for Apple Orchards.
Fig. 3 Construct risers and sprinklers for permanent irrigation systems for tree fruits as shown above.
Fig. 4 This is a typical layout for a permanent irrigation system for tree fruits.

Prepared by

Ronald E. Sneed, Professor and Extension Specialist
Water Management, Department of Biological and Agricultural Engineering

C. Richard Unrath, Associate Professor and Extension Specialist
Department of Horticultural Science
Mountain Horticultural Crops Research Station, Fletcher, N.C.

This publication is included in the N.C. Apple Production Manual. To obtain other bulletins in this series, contact the Department of Horticultural Science, North Carolina State University, Box 5216, Raleigh, NC 27650.