Container Nursery Irrigation Efficiency, Interception Efficiency and Leaching Fraction Practices

Ted Bilderback
Nursery Extension Specialist
Department of Horticulture Science
North Carolina State University
Ted_Bilderback@ncsu.edu

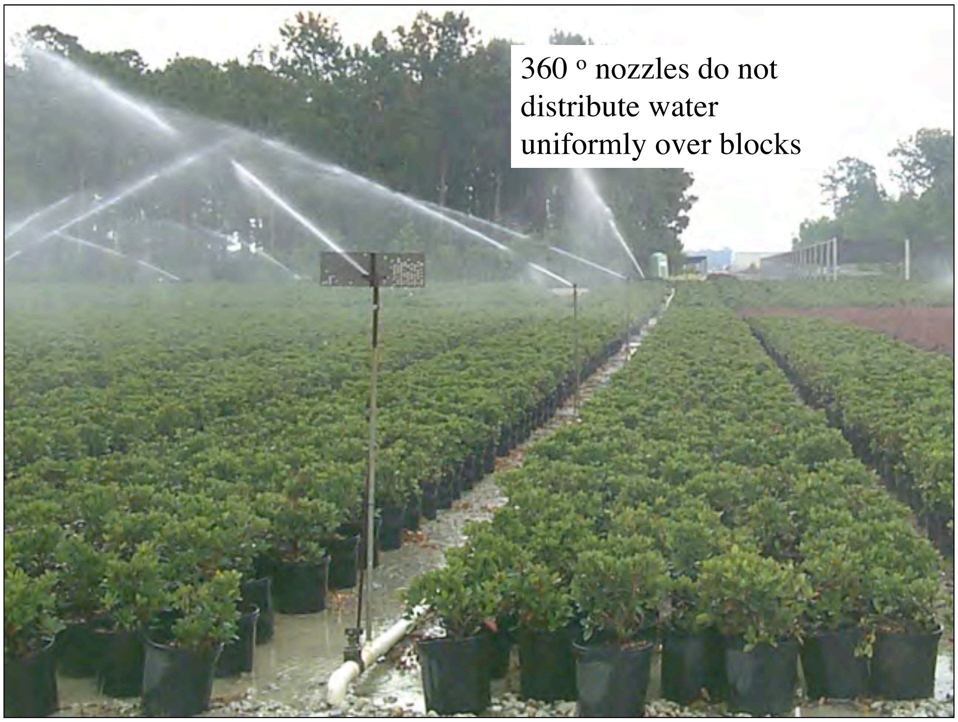
http://www.ces.ncsu.edu/depts/hort/nursery/

This presentation will highlight common irrigation distribution problems in container nurseries and discuss " Best Management Practices" which improve irrigation efficiency. Well design irrigation systems save water supply resources, electrical power used to pump irrigation supplies and reduce handling practices required to capture and recycle irrigation supplies. Additional information and presentations related to this subject can be found on the NCSU Nursery Science Website.

Irrigation Efficiency

- Water distribution pattern and uniformity are influenced by nozzle spacing and system hydraulics.
  - Irrigation designs feature rectangular spacing of risers, triangular spacing and square patterns.
  - Irrigation system must be designed to account for pressure loss/friction loss so end risers have adequate pressure.
- Well designed overhead irrigation systems under poor management result in reduced system efficiency and increased pollutant discharge.
- Efficient irrigation management should be concerned with uniform distribution of irrigation and minimizing nutrient and pesticide loss from production beds due to over application of irrigation.

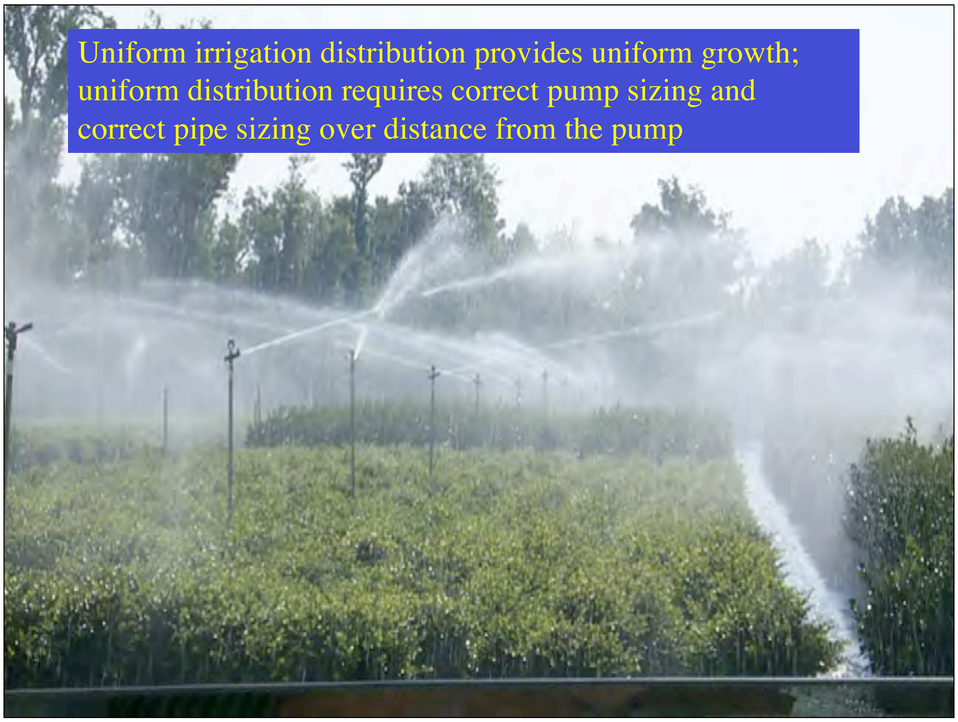
Irrigation systems should be designed by trained professionals so that pump size, main lines and distribution lines are correctly sized for the volume and pressure required and friction loss are properly calculated for uniform distribution of irrigation in overhead systems.



Most container nurseries use overhead sprinklers for irrigation of small containers including 1 gallon, 3 gallon and 5 gallon containers. Two factors, in particular, complicate container nursery irrigation management; porous substrates and the need to capture or reduce runoff. Most nurseries irrigate growing beds for a specific amount of time such as 1 hour.

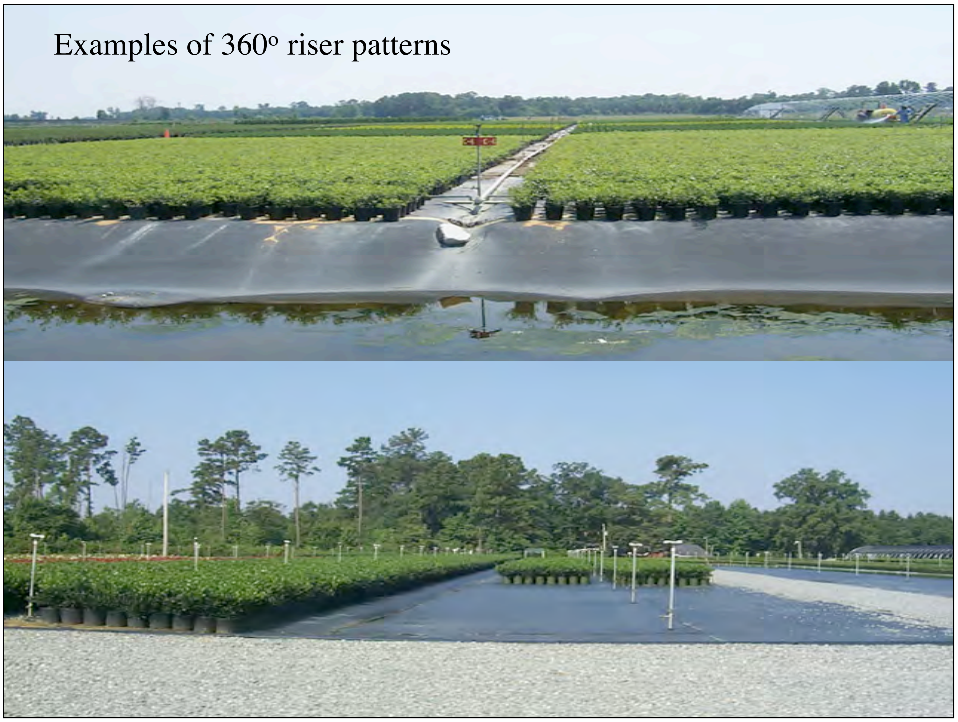
Nozzles in this container growing area rotate in a 360º pattern. The mess screen plate at the top of this bed end riser is mounted on an elbow that allows the nozzle to turn in a full circle and was installed to reduce irrigation falling on the drive road adjacent to the bed. Water observed in a pool below the risers shows the excess irrigation blocked by the screen. Containers at the edge of this bed are setting in standing water and are much wetter than containers further away from end nozzles. Plant quality may be reduced and foliar and root diseases will likely be more prevalent in these containers.

A more efficient designed irrigation system would include 180º (half circle) nozzles adjacent to drive roads.



The design of the irrigation system has the greatest effect on the uniformity of water application over a block of container crops. In this slide a rectangular irrigation design nozzles rotate over a 360^0 area. Irrigation application is always less uniform with this design. More water is applied closer to the riser and less water is applied at the edges of the pattern farthest away from the riser. Growers usually run irrigation until the driest plants at the edges of the irrigation pattern are well irrigated. Plants closer to the risers may be over irrigated. Pine bark substrates may drain well enough to not become water logged, however, nutrients may be excessively leached from containers close to risers. Growth patterns may be observed in container beds related to their location to irrigation risers.

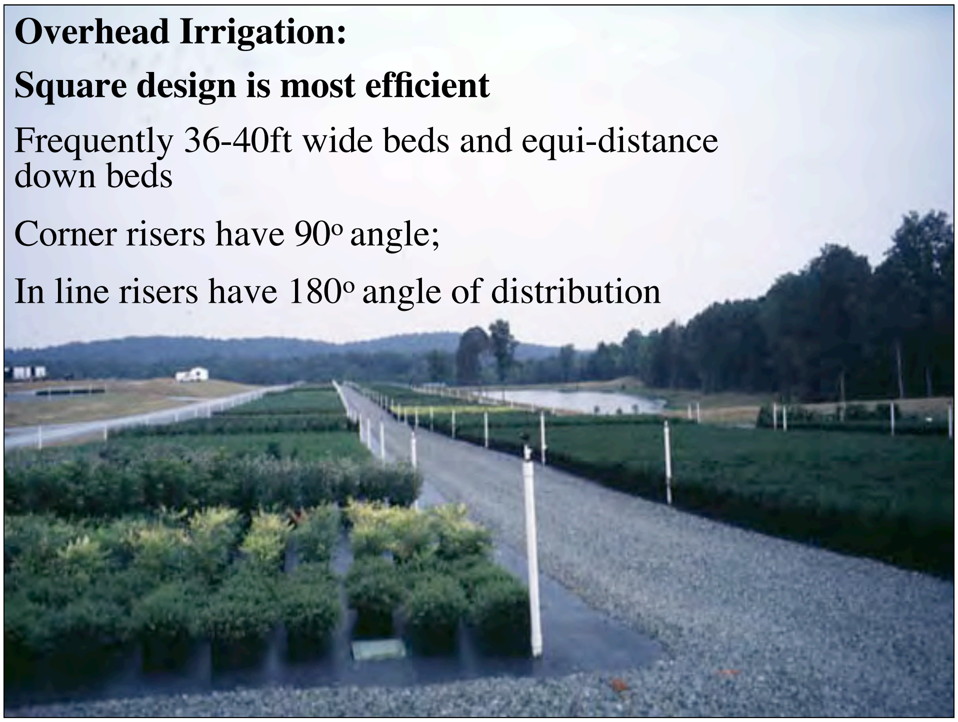
Examples of 360^o riser patterns



Full circle nozzles are used at these nurseries for irrigation of wide growing beds. Wide beds increase the percent of production space compared to non-growing space. Irrigation equipment costs are less when fewer risers are required to irrigate large areas. Irrigation zones can be increased compared to smaller bed areas with more risers. More plants can be grown in production areas with less cost of installation of beds. These container beds are sloped to the center for capture of bed runoff. Although the runoff management system works well, irrigation distribution in not as uniform as might be accomplished using a square irrigation design. Such irrigation practices were developed when water was considered to be available in unlimited supply and the highest priority was growing the most container plants per square foot of bed space.

Complete circle nozzles (360° rotation) characteristically have very low irrigation efficiency. Irrigated areas may extend from the middle of one bed to the edge of the next bed including distances of 60 feet to 80 feet wide, however, minimal overlap occurs between risers. Much of the area irrigated is not container plants but non-target areas such as roads. Poor irrigation efficiency results in large amounts of runoff from production areas that must be directed away from beds and across nurseries facilities to runoff capture structures. Large volumes of runoff may increase erosion and weed management practices are increased. Also note in this slide that not all risers are perpendicular. Tilted risers decrease irrigation efficiency since the irrigation pattern is distorted.

Triangular Riser Patterns use complete circle nozzles and fewer risers than a Square Irrigation design, therefore a triangular design is less expensive to install. Irrigation patterns are designed to overlap, but a triangular design does include distribution arcs with no overlap between risers. Bed widths may be 60 feet to 80 feet wide.



A square irrigation design is the most efficient overhead sprinkler irrigation design for most nurseries, but may also be the most expensive to install. Bed widths are usually limited to 36 to 40 foot widths, dependent upon nozzle orifices, pump capacities, pressure and water volume characteristic to the irrigation design. The irrigation pattern is designed for 100% overlap with each nozzle distributing water over the entire radius between down line risers and risers across the bed. Corner riser nozzles rotate 90^{o} while side risers rotate 180^{0}. Corner nozzles orifices apply ½ the volume applied by side nozzles orifices.

Irrigation of some production areas in nurseries are difficult to irrigate efficiently. Full circle nozzles are most frequently used for irrigating winter protection structures (upper left and lower right pictures). However, poor uniformity is a problem when houses are covered with plastic. Plants located in the ends and corners of winter protection houses are frequently dry since circular irrigation patterns do not irrigate square corners efficiently. The plastic cover also disrupts irrigation patterns, creating very wet areas below where water strikes the plastic and dry edges where irrigation does not reach containers close to the outside wall of winter protection structures. During the growing season, these winter protection houses are uncovered and are used as growing areas. Irrigation efficiency is less than desirable under production conditions as well.

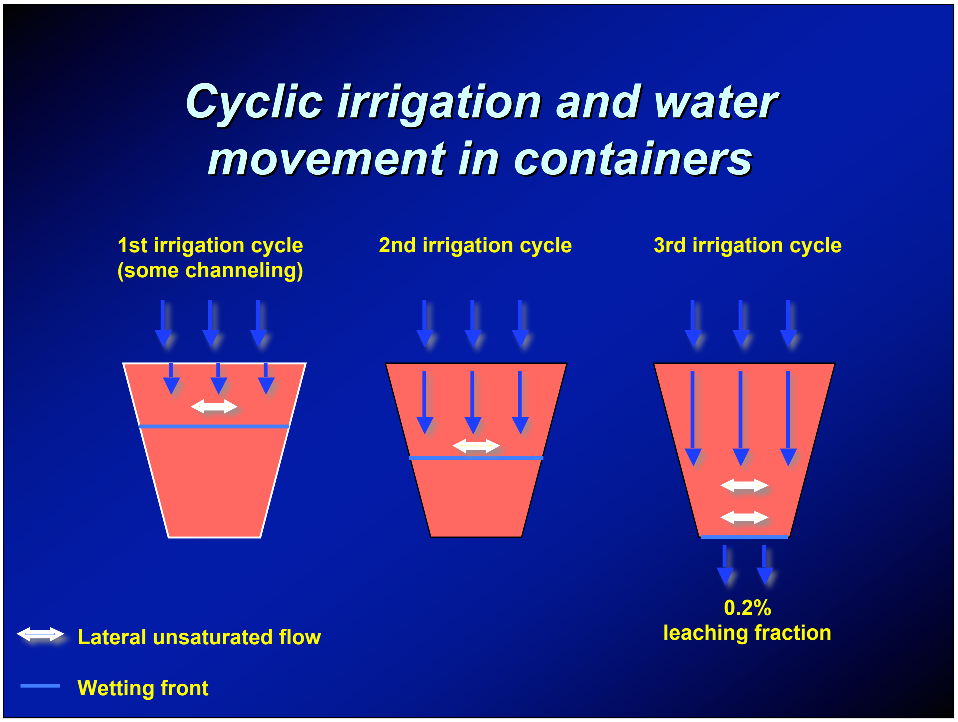
A variety of overhead sprinkler nozzles types are available. In this slide, the rotation pattern of the nozzle can be adjusted to cover a particular area. However, water volume applied is not adjustable, therefore, irrigation application is not as uniform as impact sprinklers designed to cover specific areas.

Rain sensors on automated landscape irrigation systems are mandatory in some communities. Likewise, rain over ride sensors should be installed on automated nursery irrigation systems. The notches at the top of the sensor can be set to over ride irrigation system after ½ inch or 1 inch of rain fall.

Irrigation riser shut off valves allow growers to shut irrigation off when beds are empty between crops.

Cycled Irrigation: Using several short intervals vs one long cycle saves water & energy but usually requires automated irrigation control and uniform

Cycled irrigation is the use of multiple irrigation cycles of irrigation compared to one long irrigation cycle. Automated controllers and electric solenoids are required for cycled irrigation, since turning manually operated valves multiple times over many irrigation zones in a nursery is impractical. Cycled irrigation requires uniform irrigation distribution. Consequences of poor irrigation distribution are magnified when cycled irrigation is used.



Multiple irrigation cycles with a programmed rest cycle (30 minutes to 2 hr) between irrigation applications moves a wetting front through the profile of the container. Between cycles, water above and around the wetting front wet adjacent substrate particles eliminating dry pockets within the substrate. The last irrigation cycle is run for enough time to push the wetting front to the bottom of the container with an excess of approximately 20% (0.2 LF). Research has shown that for pine bark substrates, an excess of approximately 20% leaching is required to fully wet the entire volume of substrate in the container.

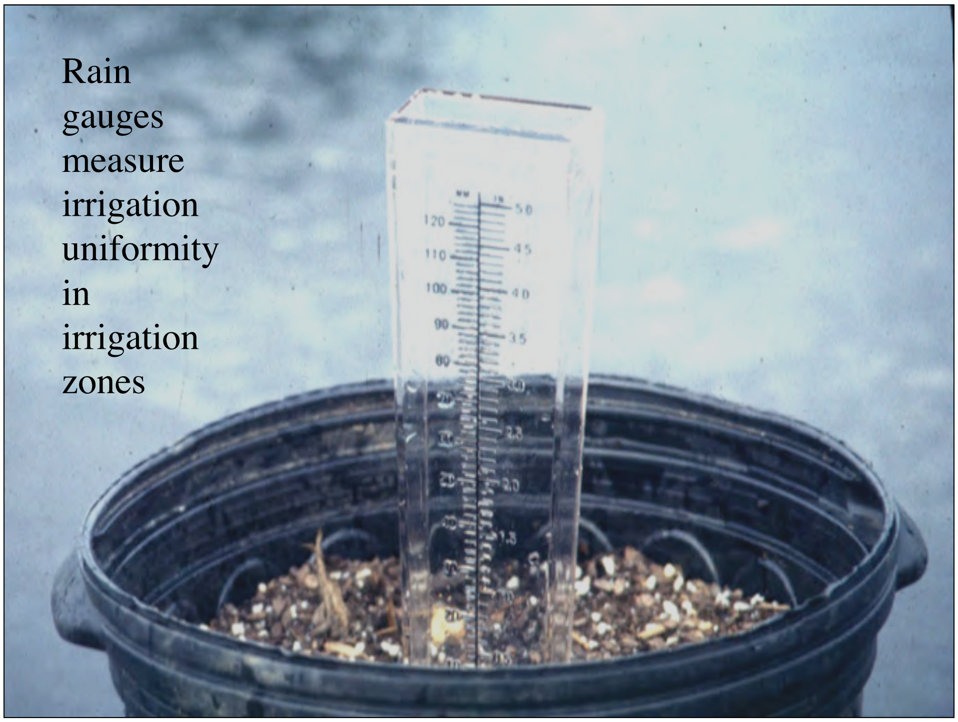
Interception Efficiency (IE)

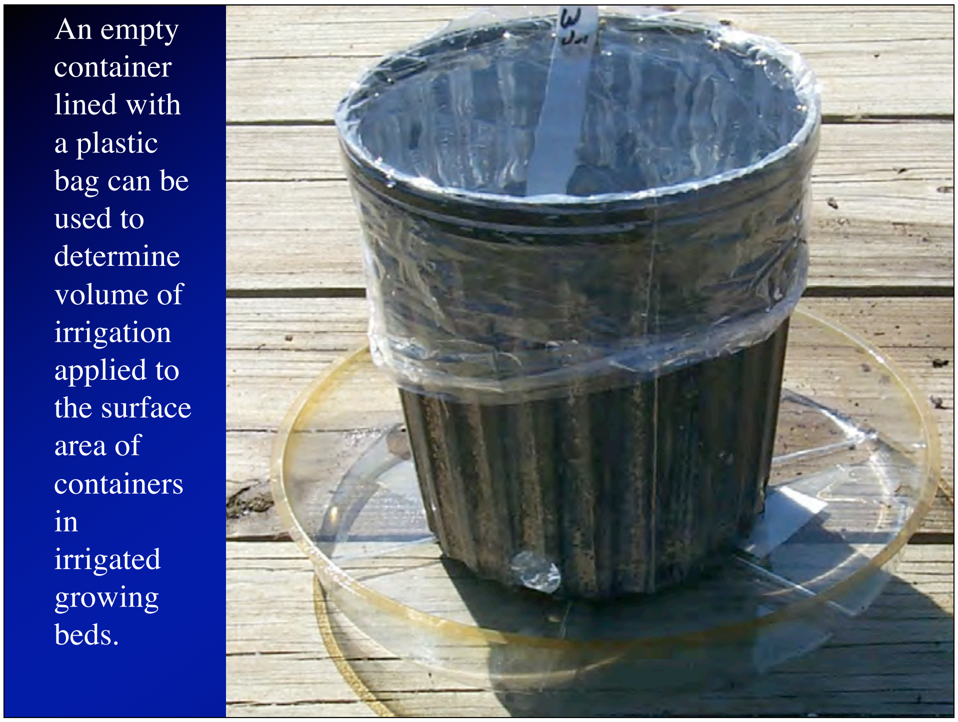
- Several methods proposed for determining Interception Efficiency.
  - Measure water applied to area occupied by containers.
    - Collect and measure irrigation in rain gauges or by straight sided containers.
    - Insert a plastic liner in fallow containers in the irrigation zone.
  - Calculate water applied by nozzles based upon specified volume of nozzle and pressure.
  - Install a water meter at pump and record water used for each zone; calculate water volume applied to area of zone.
  - Saturate several containers, bag containers, irrigate, and measure volume in plastic bag after irrigation and drainage.

Interception efficiency is usually expressed as a percentage of the applied water, but can be calculated theoretically in terms of area. Interception efficiency is defined as the container top surface area divided by the ground area allotted to a single container, and is expressed as a percentage value. Interception efficiency integrates plant density, container size (volume) and irrigation method.

Installing a Water Meter on Irrigation Pumps provides information on water use.

Water meters are not standard equipment on most nursery irrigation systems due to cost. However, water meters are an excellent investment because they provide information on daily water use. Data recorded from water meters can be used to determine water applied for calculation of interception efficiency in container beds.


Rain
gauges
measure
irrigation
uniformity
in
irrigation
zones



Plastic bags can be used to line pots to create a water tight container to conduct leaching fraction and interception efficiency studies.

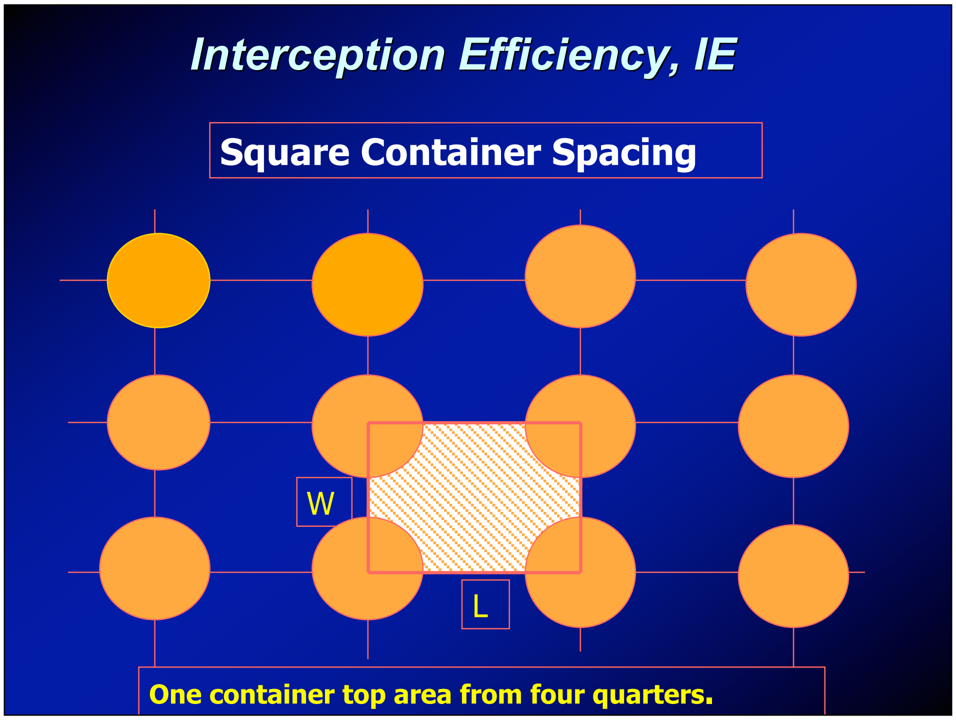
At NCSU, we have chosen to use 1 gallon paint buckets for leaching fraction data collection. The buckets in these pictures are line up for a picture, but to determine leaching fraction and interception efficiency, they should be placed in beds at the same spacing as plants in production.

Interception Efficiency

- For overhead irrigation of containers, interception efficiency (IE) is defined as the amount of water that enters the container compared to irrigation falling between containers..
- The amount of water intercepted (IE) by containers depends on the container spacing, amount of space between containers and crop canopy.
- Uniformity of irrigation system effects irrigation efficiency
- Duration and frequency of irrigation is affected by crops, container size and mix of crops in the irrigation zone
- Multiple types of crops within the same irrigation zone will usually have different interception efficiencies related to the crop canopy architecture.

Irrigation efficiency is a broad measure of the amount of applied water that is captured by the container during an overhead irrigation event.

Interception efficiency (IE) is a specific method of calculating irrigation efficiency within a container production area. IE is defined as the container top surface area divided by the ground area allotted to a single container. IE is expressed as a percentage value. Spaced containers may have an IE less than 50%, meaning that 50% or more of the water applied does not enter containers. Many factors including wind and other environmental, irrigation design, container spacing and size of containers effect irrigation efficiency. These same characteristics as well as factors such as plant canopy architecture have significant effect on interception efficiency.



- Interception efficiency is defined as the container top surface area divided by the ground area allotted to a single container, and is expressed as a percentage value. The interception efficiency (IE) of a container is the percentage of water captured by a container compared to the amount applied to the container and the open space around the container. When overhead irrigation methods are used and containers are spaced apart, a percentage of water enters the containers.

- Note that four quarters of a container are in the rectangle to represent one container top area. The rectangle area (L x W) is the ground area allotted to each container. The container top area is simply the area of a circle or 0.785 x diameter x diameter.

Leaching Fraction
Management Unit 3 gallons
Substrate- 6 Pine Bark- 1 Builders Sand

Container	#1	#2	#3	#4	#5	Average
Plant Container	250 ml	225	160	275	210	224
Empty Container	775ml	740	770	870	760	783
Leaching Fraction	32%	30%	21%	31%	28%	29%

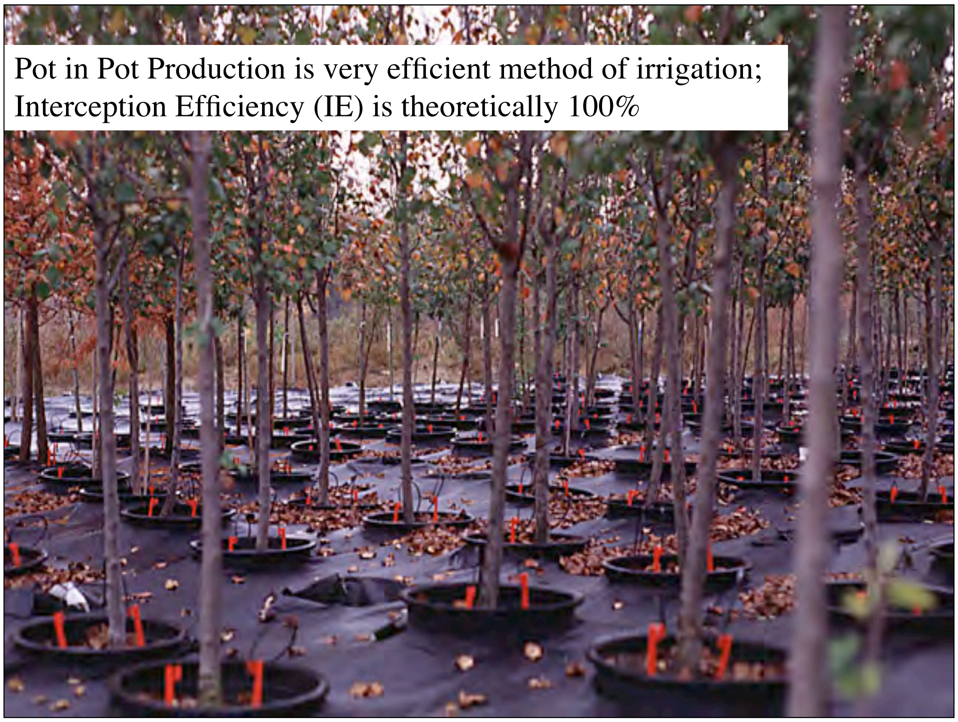
The goal is to minimize the measure leaching fraction. Values under 20% are good. The amount and type of fertilizer salt (N or P) being tested used will determine the safe low value

Newly potted container set at close spacing improves interception efficiency and reduces high root zone temperatures due to shading from adjacent containers.

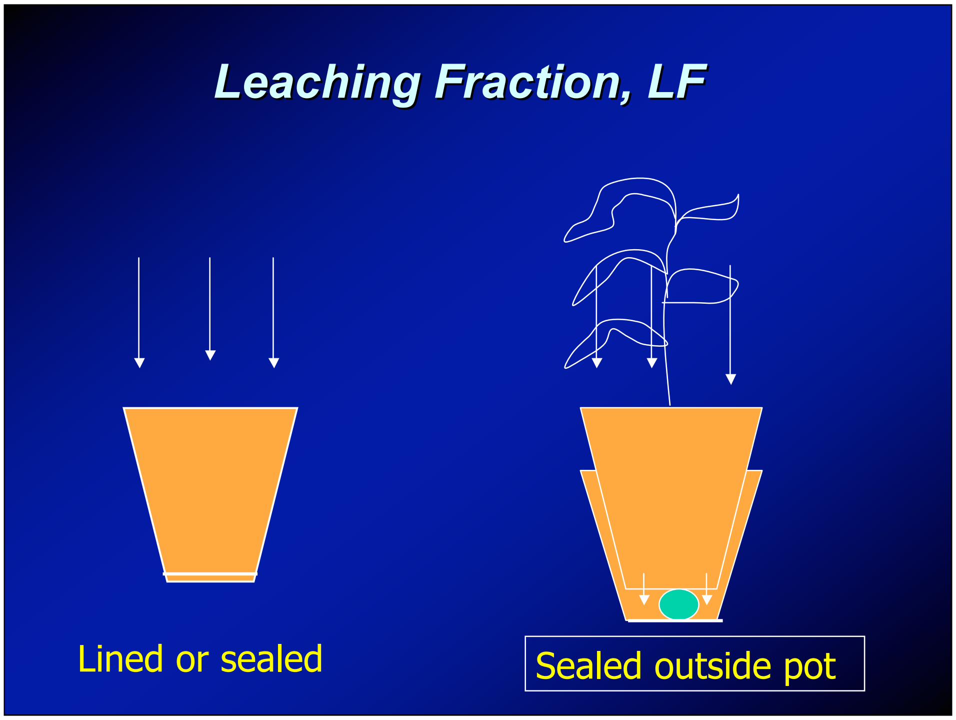
Wide spacing of containers reduces labor required during the first season to spread containers at mid-season, however interception efficiency is reduced since more water falls between containers. Runoff volumes are also increased with wide spacing as more irrigation falls between containers.

Note in this slide the variety of crops being irrigated in the same zone. At least four types of crops are in this same zone including blue rug juniper, which is a conifer; japanese barberry, which is deciduous; and buddleia, which is a perennial. Do these crops all have the same irrigation requirements? How can a grower manage irrigation if multiple crops with multiple irrigation requirements are located in the same irrigation zone? Which of these crops needs the most water and which need less water?

•When low volume irrigation is used, all the water enters the container and IE is 100%



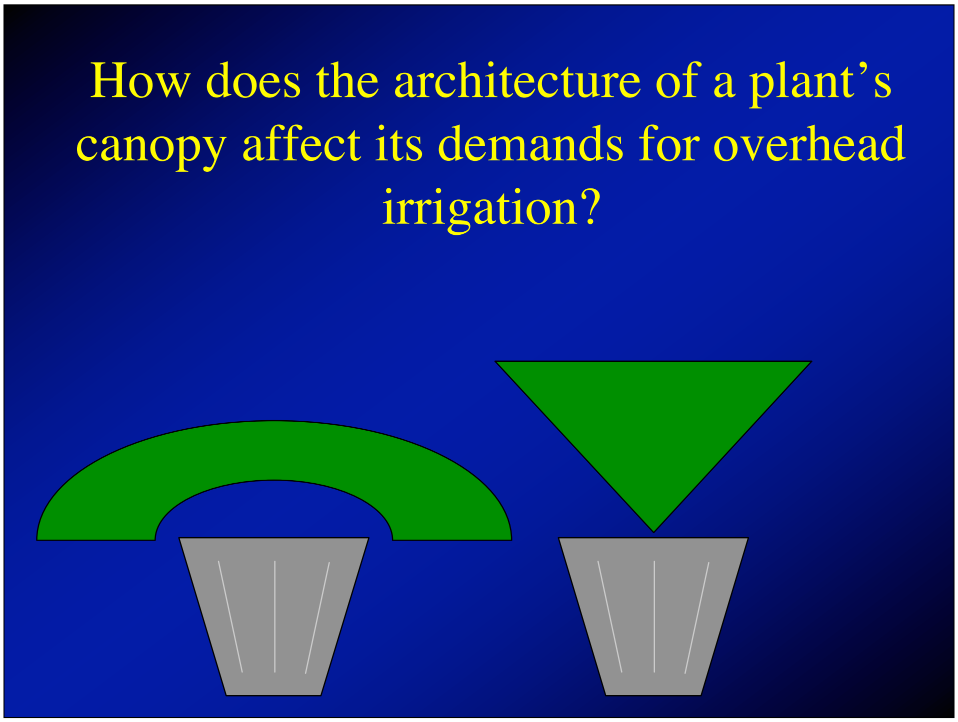
Pot in Pot is an example of low volume irrigation where IE would be equal to 100% unless spray stakes over spray the side of containers. Where low volume systems are used, LF becomes the most important contributor to the potential runoff (PR) value.



•Leaching fraction compares the amount of leachate to irrigation water applied. LF is determined primarily by container HEIGHT (gravitational potential) on water column. Note that an object is placed in the bottom pot to raise the plant pot above the bottom of the container so that the bottom of the plant container is not immersed in the leachate collected. Stones or a brick can be used to elevate the container above the leachate collected. The same practice can be used for the empty containers.

Leaching Fraction (LF) is the proportion of applied water that leaches from a container after an irrigation event.

LF (%) = leachate volume (ml) / Total irrigation volume (ml) x 100



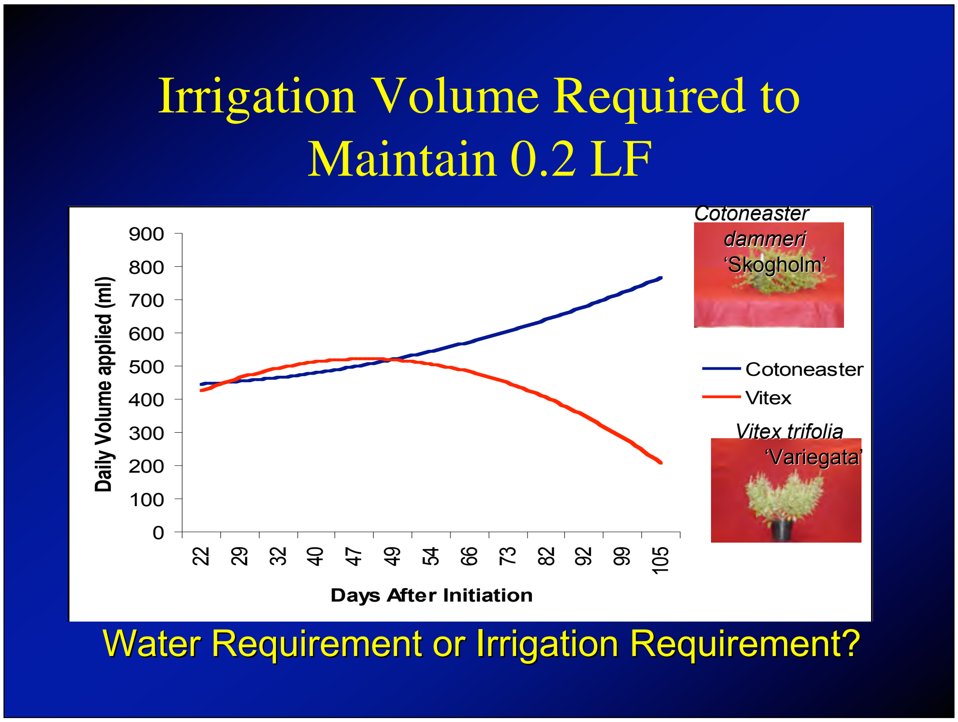
Plant Architecture does change the amount of water that enters a container!

Gardenia has a vase or funnel shaded canopy. After approximately 100 days of a growing season, gardenia intercepted approximately 240% more water than was collected in empty containers of the same diameter.

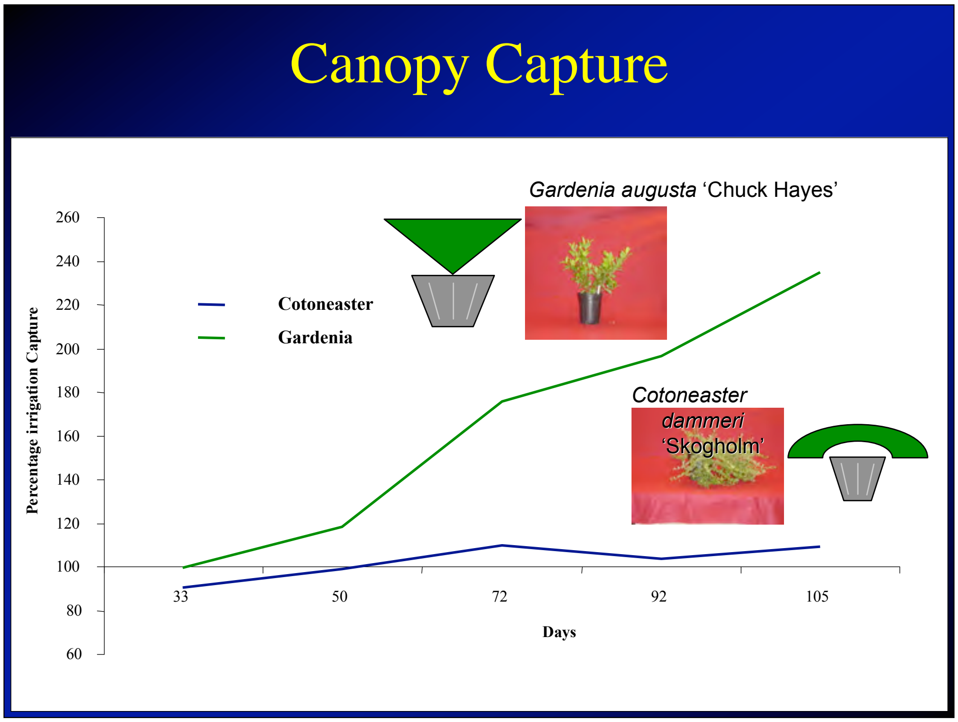
Plants with umbrella shade canopies may reflect water away from entering the surface area of containers. In this case, leaching fractions are reduce and Interception Efficiency is reduced. Potential Runoff would be increased in cases where water is deflected from entering containers. Research at NCSU has shown that cotoneaster seen in this slide has no effect on leaching fraction. The reason is presumed to be that leaves are small and do not deflect irrigation droplets.

Measuring LF for overhead irrigation

In research studies at NCSU, 1 gallon paint buckets have proven to be a good fit for 1 gallon (3



The figure shows that as the Cotoneaster (blue line) grew from 22 days to 105 days daily irrigation required to maintain a 0.2LF increased from approximately 450 ml to over 700 mls. In contrast, the Vitex required less water over the growing season from approximately 400 mls on day 22 to approximately 200 ml on day 105. In reality, Vitex did not need less water as it grew, it simply captured more water beyond the edge of the container due to a funnel type architecture.



The figure shows the amount of water captured by the canopy of two nurseryl crops over a growing period of 33 day to 105 days. The cotoneaster maintained approximately 100% of the water applied (compared to an empty container) while the ‘ Chuck Hayes’ gardenia gather as much as 240% more water than was collected in an empty container.

Potential RunOff

- Potential Runoff (PR) is the estimated percentage (or volume) of maximum daily-applied water that runs off a site. Potential runoff is calculated from LF and IE and provides a useful measure of the estimated runoff from nursery production areas. It therefore will help estimate containment area capacity or the daily volume of water delivered into a riparian area or containment structure.
- Potential runoff is estimated by the following equations:
  - Potential Runoff (volume) = Total Applied Water x [1.00-IE) + (IE x LF)] or
  - Potential Runoff (%) = [1.00-IE) + (IE x LF)] x 100 where IE and LF are expressed as fractions (not %).

Potential runoff is made up of water that leaches through containers plus the water that is not intercepted by containers. The IE value is particularly important in those operations that fertigate (i..e. the application of soluble nutrients in irrigation water). The value (100-IE) is the percentage of irrigation water or fertigation solution that falls directly onto the ground, which contributes more directly to nutrient runoff than LF. In greenhouse operations, where IE is usually very high (as containers are closely packed) or where low volume systems are used, LF becomes the most important contributor to the potential runoff (PR) value.

Sample data table for average LF,IE and PR data for a hypothetical nursery

Managed Unit	Crop	Container Size	LF	IE	PR 1-IE + [LF x IE]
A1	Annuals	Plugs	12%	90%	21%
H1	Herb/ Perennials	< 1 gal	24%	80%	39%
W2	Woody Plants	1-3 gal	26%	60%	56%
W3	Woody Plants	4-7 gal	36%	28%	82%

The risk of nutrient leaching in growing operations is weighted either by LF or IE, or both factors when irrigation management is poor and containers are widely spaced (unjammed).

Irrigation Time of Day

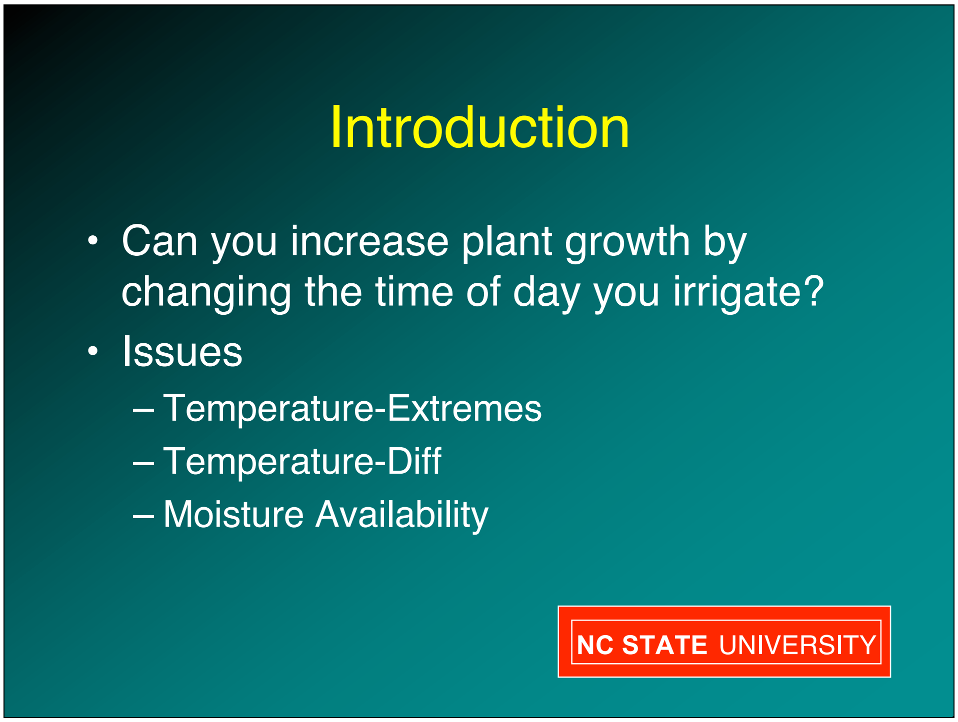
Does It Really Matter ?

Stuart Warren and Ted Bilderback
Department of Horticultural Science
North Carolina State University

NC STATE UNIVERSITY

This research was conducted at N.C. State University in 1999 and 2000. Details can be found in the following publication:

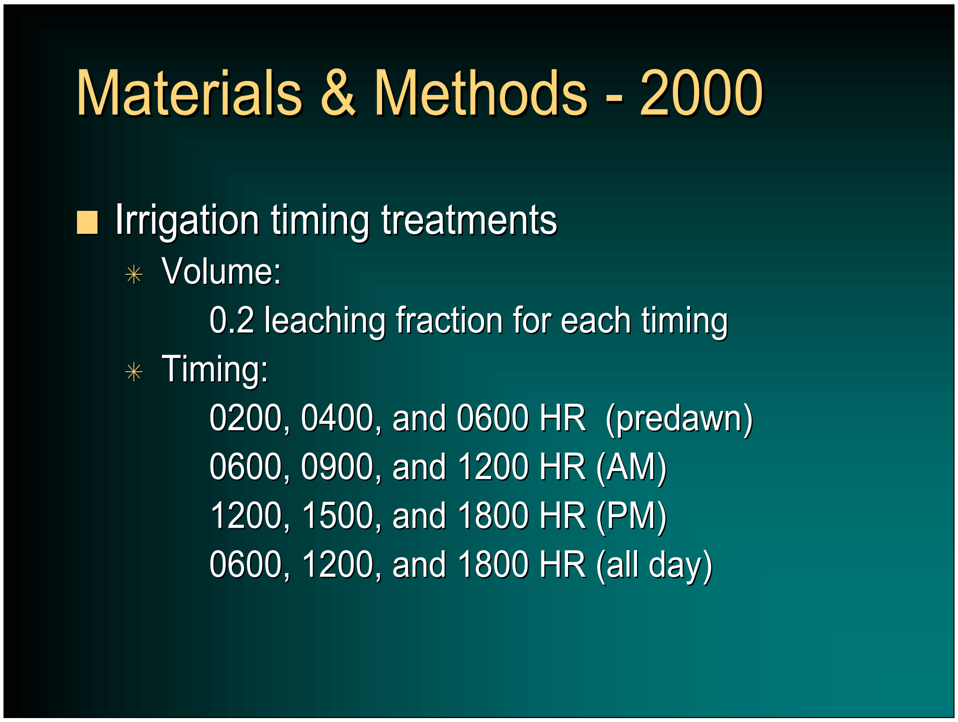
Warren, Stuart L. and Ted E. Bilderback. 2002. Timing of low pressure irrigation affects plant growth and water utilization efficiency. J. Environ. Hort. 20(3):184-188.



Irrigating plants in the middle of the day may be a possible way to reduce moisture stress and reduce high temperatures. Recommended practices of early morning irrigation may actually depress temperature at a time that ambient temperatures are optimal for shoot growth, thus reducing maximum growth. Will time of irrigation make a difference? See the next slides!

Research was conducted at the NCSU Horticulture Field Lab on the Nursery Research water and nutrient collection facility

All leachate run off is captured from 16 beds in this research unit. The facility allows development of total water and nutrient budgets. For instance, some studies resulted in 400 ml are required to 1 gram of cotoneaster dry weight. Other work has provided data on irrigation and nitrogen efficiency.

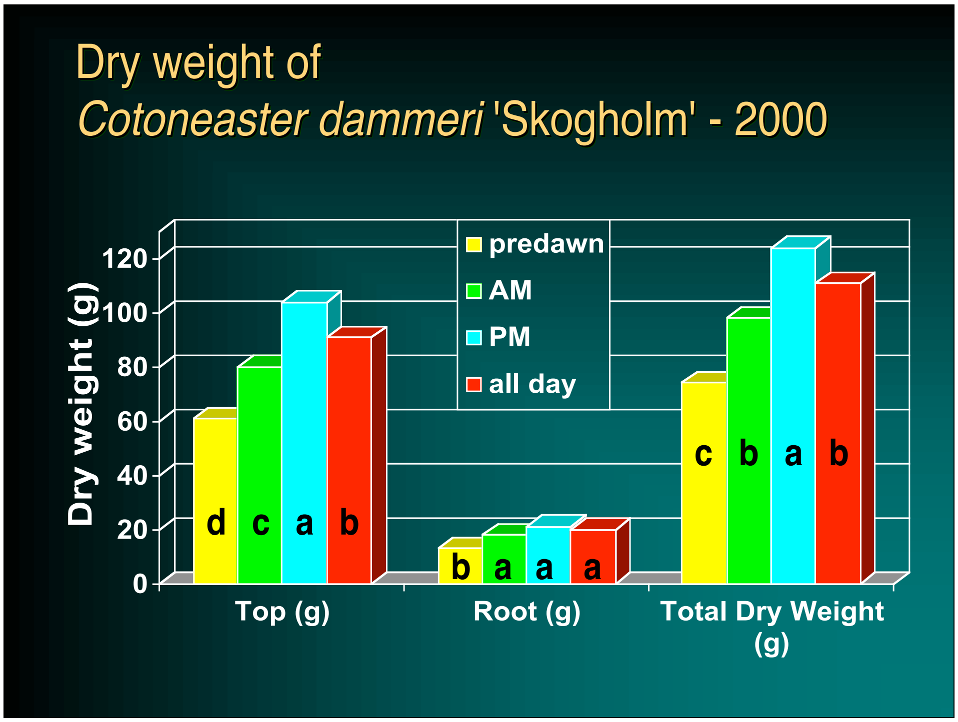


A 0.2 leaching fraction was monitored and adjusted at least twice a week. The effects of the time of day irrigation was applied was the focus of the study.

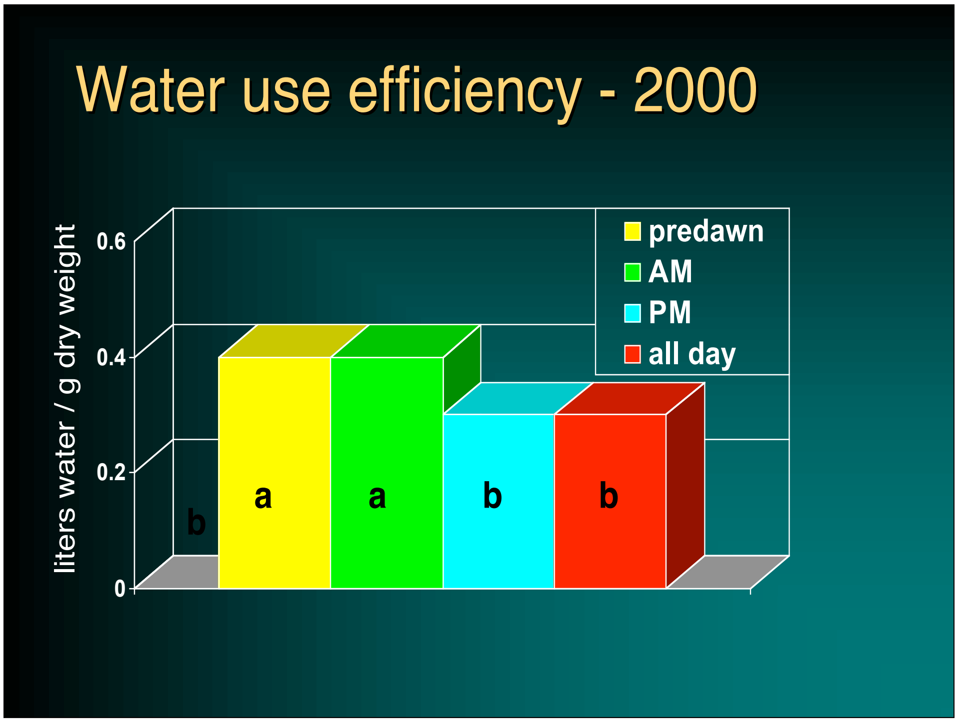
Results - 2000

Irrigation timing	Volume applied (L)	Volume leached (L)	Leaching fraction
Predawn	18.7	3.6	0.19
AM	26.4	4.0	0.15
PM	27.5	3.3	0.12
All day	26.4	3.2	0.12

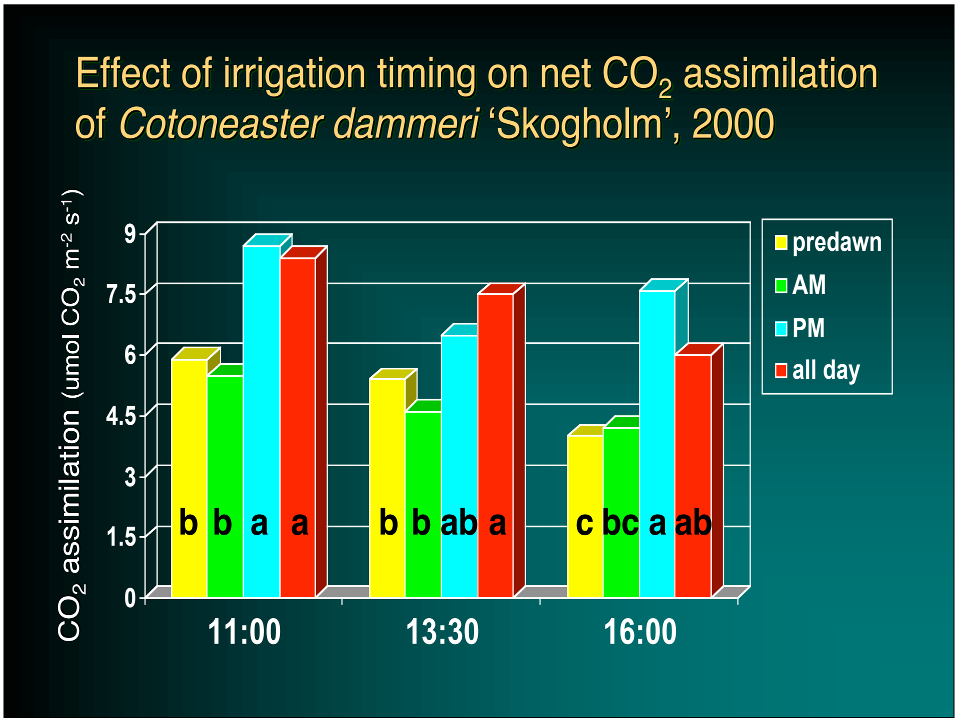
This table shows the average daily amount of water applied and leached for each time of day irrigation treatment and the average leaching fraction maintained during the study.



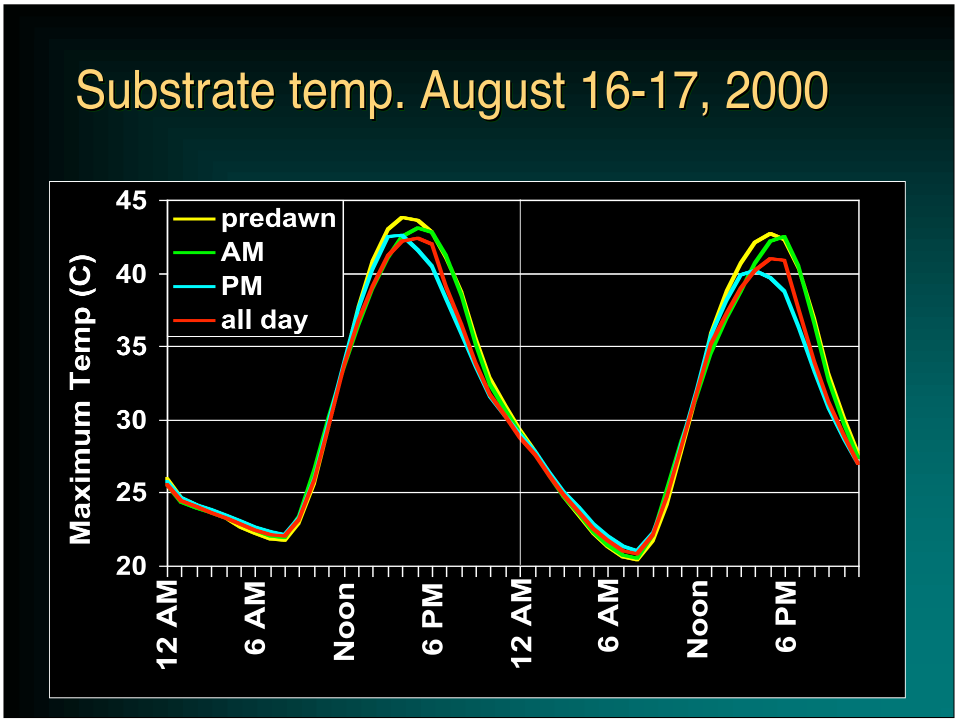
Plant growth was greatest when plants were irrigated in the afternoon during the hottest part of the day. Plants were smallest when irrigated during pre-dawn hours.



The figure above shows that PM and All Day irrigations required less than 400 ml per gram of dry weight, while plants grown with predawn and AM irrigation required more than 400 ml per gram dry weight.

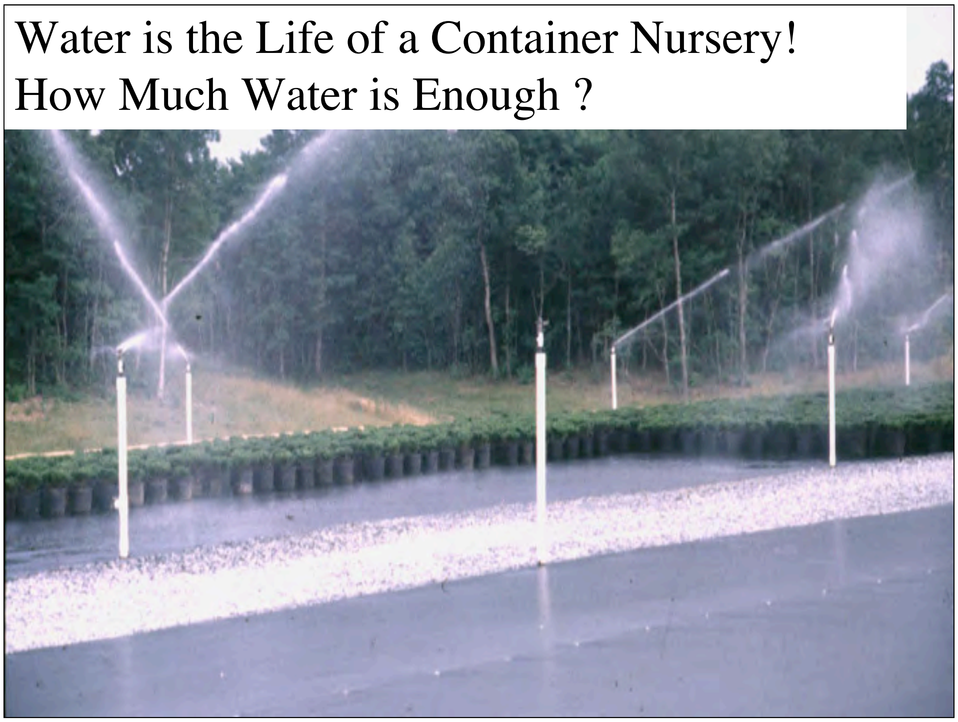


When net CO_2 assimilation (Photosynthesis rate) was evaluated at 11 am, photosynthesis was highest in plants that had not been irrigated since the evening before compared to plants that had received recent irrigation. Ultimately, plants that are stressed never have as high photosynthic rate as unstressed plants.



Temperature data showed that predawn and AM plants had significantly higher root zone temperatures throughout most of the afternoon and evening hours compared to PM and All Day irrigated plants.

Don’t have a cat yet! There is more exciting information following this slide!



How much water do nurseries need?

Water Supplies

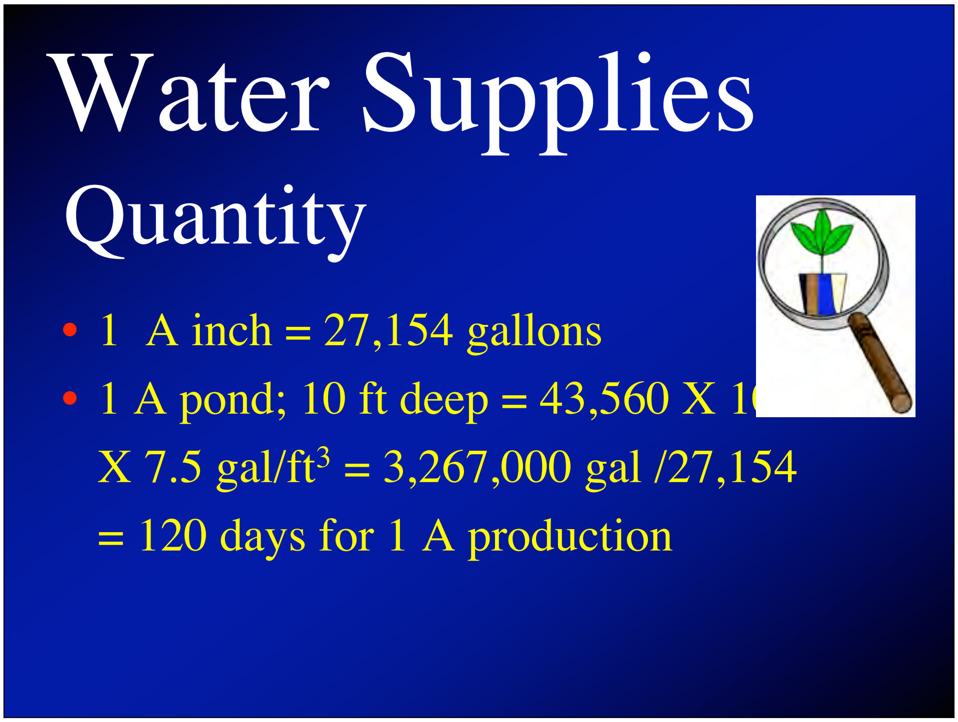
Planing for Enough

1 to 5 Gallon Containers-Overhead Sprinklers

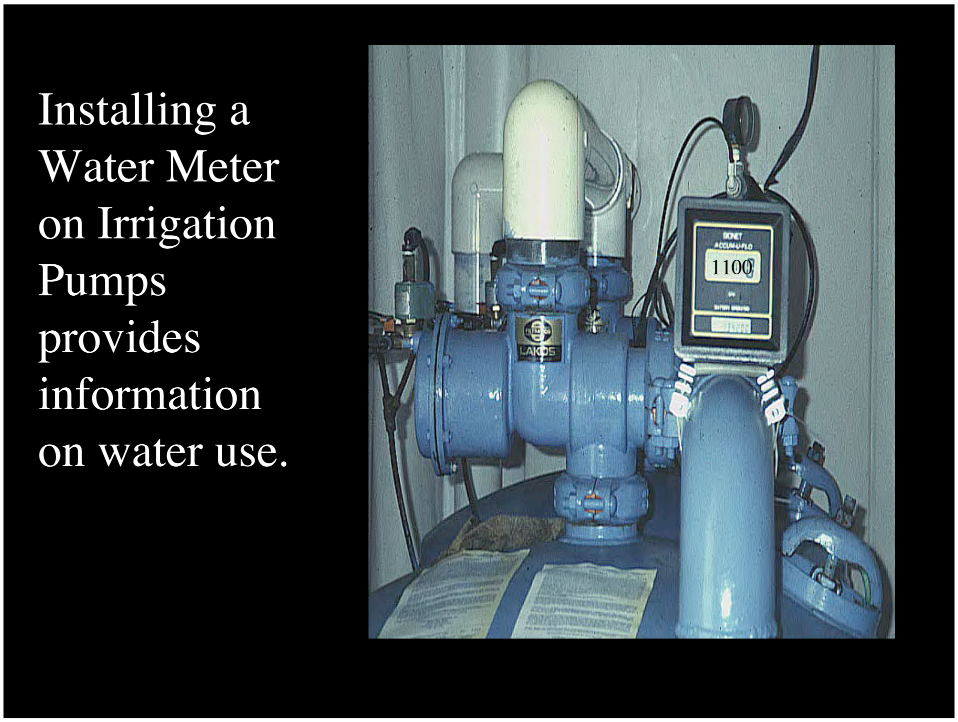
- Plan 1 Acre Inch/Acre/Day-60 Day Supply
- Plan Storage for 5 to 10 Acre Feet/Acre/Year
- If irrigate 163 days/yr = 4.3 million gallons/A
- Actually probably need 1/2 this supply

Text book references suggest that nurseries should plan for 1 Acre inch (27,000 gallons of water) for every acre of production for each day of irrigation.

One mistake many nurseries have made is expanding growing bed space without expanding water supplies. The drought during the summer of 2002 found many nurseries short on irrgation.



Water storage estimates can be made by determining the surface water area in square feet and multiplying the surface area by the average depth of the storage structure to determine total cubic feet of storage capacity. Storage capacity in cubic feet can be multiplied by 7.5 gallons (1 cubic foot of water) to determine storage capacity in gallons.



Use of a water meter is the best way for a nursery to determine their daily water needs and to evaluate the efficiency of water conservation practices.

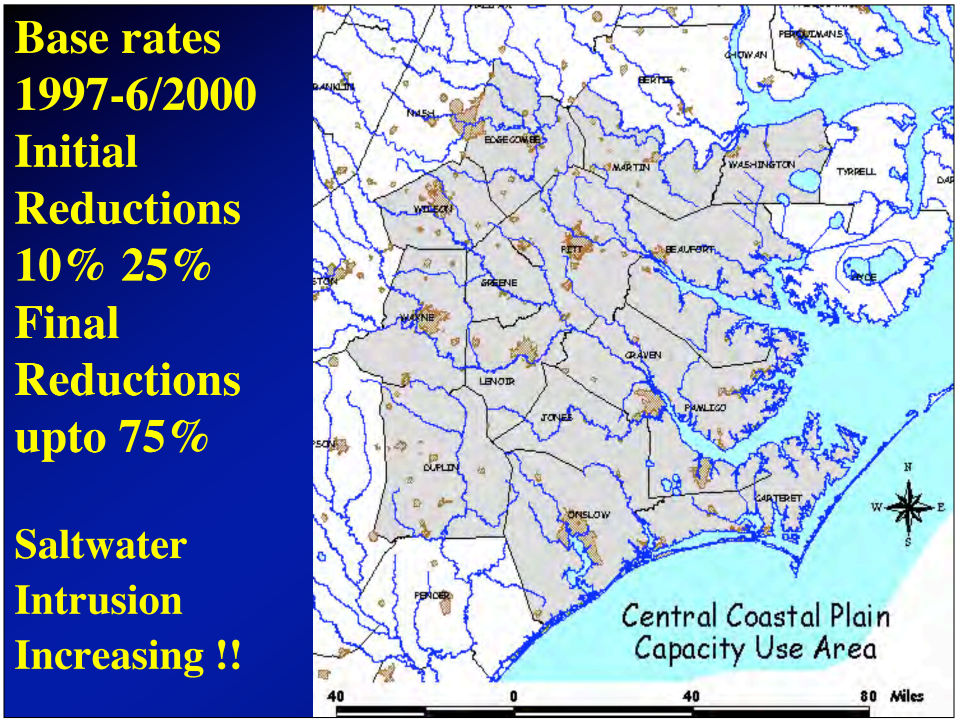
Water Supplies

- **Ground Water - Deep Aquifers**
  - **Central Coastal Plain Capacity Use Area**
  - **15 Eastern N.C. Counties**
- **10,000 gpd Withdrawl Permits**
  - **Quarterly reporting**

http://www.dwr.ehnr.state.nc.us/Permits_and_Registration/Capacity_Use/Capacity_Use_Area_1/

http://www.dwr.ehnr.state.nc.us/Permits_and_Registration/Capacity_Use/Central_Coastal_Plain/

North Carolina does have locations with water use restrictions and water use reporting requirements.



Aquifer withdrawls during the 1990's were so great that salt water intrusion was increasing in the deep aquifers. Consequently a capacity use area in Eastern NC has been established where withdrawls are limited

Water conservation and availability are now conscious decisions in development of nurseries in North Carolina

Water Supplies

- **Shallow Ground Water**

  Coastal Plain Areas of N.C.
  - Approximately 50 to 70 feet deep
  - Impurities Common-
    - Iron
    - Boron
    - Bicarbonates

In Eastern NC, shallow wells offer some water resources, however, the water quality is often not as high are required for production of container grown nursery stock. Shallow water may require treatment or dilution to be feasible for use for growing nursery stock in containers.

Water Supplies

- **Surface Withdrawls in NC**
  - Rivers, Creeks- Riparian Water Rights
  - Storage/ Retention Structures
  - Register Withdrawls (Future Permits)
    - –> 1,000,000 gpd
  - Quality subject to upstream discharges

In some parts of the NC, daily use of 100,000 gallons of water from any water supply requires permit or monthly reporting. Any use of >1,000,000,000 gallons requires registration.

Most nurseries in NC utilize surface water supplies and grade nursery properties to capture as much bed run off as possible and the first ½ to 1 inch of stormwater.

Most nurseries in NC have not begun to directly capture stormwater from structures but horticultural operations with large roof expansions could capture significant volumes of water. In this slide a rubber bladder has been floated on a canal adjacent to a greenhouse. The floating bladder collects rainwater from the greenhouse.

That’s All Folks!