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Efficiencies of Irrigation Systems Used in Florida Nurseries¹

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Irrigation efficiency is a measure of (1) the effectiveness of an irrigation system in delivering water to plants or (2) the effectiveness of irrigation in increasing plant production. From definition (1), irrigation efficiency may be expressed as the ratio of the volume of water used or available for use in plant production to the volume pumped or delivered for use. From definition (2), irrigation efficiency may be expressed as the ratio of crop yield or increase in yield over nonirrigated production to the volume of irrigation water used. For nurseries, yield can be expressed as a number of marketable plants. It should be also noted, that time required to produce a marketable plant may decrease due to efficient irrigation. In this case, a time factor should be included as yield increase due to irrigation. Irrigation efficiencies thus provide a basis for the comparison of irrigation systems from the standpoint of water beneficially used (or conversely, water wasted) and from the standpoint of yield per unit of water used.

No irrigation system will apply water without some waste or losses because the cost to prevent all losses is prohibitive. Thus, some water losses are expected and accepted in proper irrigation system

design, installation, and management. However, excessive waste may be caused by poor irrigation system design, improper installation, poor management, and equipment failures. Waste may occur as nonuniform water applications, excessive applications, evaporation or wind drift during application, surface runoff or subsurface (lateral) flow from the irrigated area, canal seepage, percolation below the root zone, evaporation from the irrigation distribution system, leakage from defective pipe connections, or other losses.

It is not possible to apply the exact amount of irrigation water required with perfect uniformity because of variations in soil properties, variations in irrigation system components, pressure losses in systems due to friction and elevation changes, or other causes. When the correct average amount of water is applied, nonuniform water applications waste water due to excess applications in some areas while plant yields may be reduced due to inadequate applications in other areas.

Water may be lost due to evaporation or wind drift during application, especially for sprinkler and

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spray types of irrigation systems. However, evaporation during sprinkling cools the plant canopy, thus it reduces transpiration and partially compensates for evaporation losses.

Surface runoff, subsurface flow from the irrigated area, canal seepage, percolation below the plant root zone, and evaporation from a water distribution system during application will reduce irrigation efficiencies. Conversely, recovery and reuse of surface runoff and subsurface water will increase irrigation efficiencies.

Irrigation efficiencies vary with the type of irrigation system and with many other factors such as soil, plant, and climate characteristics, as well as with the level of maintenance and management of the irrigation system. The type of irrigation system used and the intended level of irrigation efficiency will partially depend on the availability and value of water for irrigation. Thus, economic factors will influence the irrigation efficiency sought or obtained in a specific production system. Estimates of irrigation efficiencies are required by consultants and system designers and managers so that irrigation systems can be properly designed and effectively managed to meet the objectives of an individual production system.

Most of the irrigation systems used in Florida's container and field nurseries are pressurized irrigation systems, sprinklers or some type of microirrigation. Microirrigation is sometimes used in field production or in the larger, 3 gallon and more, container production systems. However, the majority of Florida nurseries use overhead sprinkler systems. Typically, the application efficiencies of these systems are low due to the necessary container spacing. The use of impermeable surfaces allowing for water collection and recycling can significantly increase the efficiency of existing systems in sprinkler irrigated container production. However, these can be costly and often may require significant adjustments, such as land grading and reservoir construction. Recycling is not always possible, especially when land availability is a limiting factor.

Efficiency Definitions

There are many meaningful definitions of "efficiency" which relate to irrigation and plant water use. In general, the term "irrigation efficiency" refers to "the ratio of the volume of water delivered by an irrigation system." In the case of a nursery, it is "a volume of water delivered to the pots, to the volume that is input to the irrigation system." Irrigation efficiencies can be defined for components of irrigation systems, for an irrigated zone or for entire nursery-scale irrigation systems.

The term "crop water use efficiency" normally refers to the ratio of crop yield to the volume of water used to produce the crop. In nurseries the crop yield can be expressed as a number of marketable plants. The term "irrigation water use efficiency" normally refers to either (a) the volume of water beneficially used relative to the volume delivered from an irrigation system, or (b) the increase in crop yield over nonirrigated yields relative to the volume of water applied by an irrigation system.

Because of the many efficiency definitions that are used, it is necessary that efficiency terms be clearly defined for each specific application. The following paragraphs present commonly used efficiency definitions.

Irrigation Efficiencies

Irrigation System Components

Reservoir storage efficiency (E_s). Reservoir storage efficiency is the ratio of the volume of irrigation water available from an irrigation reservoir to the volume of water delivered to the reservoir. This ratio is normally less than 1.0 because of seepage, evaporation, and transpiration losses.

The amount of seepage loss will strongly depend on the properties of the materials from which the reservoir is constructed. Seepage losses may be reduced by lining reservoirs with impermeable soils (typically clays) or man-made liners such as plastic sheets. Metal, plastic, or fiberglass tanks may be used as reservoirs to eliminate seepage losses, but the cost of tanks is often prohibitive for the volumes of water required for irrigation.

Evaporation losses can be eliminated by covering the water surfaces, but this is not practical except for tanks or small reservoirs. Evaporation losses from field scale reservoirs can be reduced by designing reservoirs with smaller surface areas and greater depths. Because evaporation is a surface process, less water will be evaporated from deeper reservoirs because less will be exposed to the atmosphere. Shallow water areas also heat up and evaporate at higher rates than deep areas.

Transpiration losses from a reservoir occur as a result of vegetative growth in and around the reservoir. These losses can be reduced by preventing or minimizing growth in and near the reservoir. Vegetative growth along the shoreline can be reduced by minimizing shallow water areas. Some vegetation, especially grasses, will normally be required to stabilize the soil embankments and prevent sediment transport into reservoirs.

Water conveyance efficiency (E_c). Water conveyance efficiency is the ratio of the volume of water delivered for irrigation to the volume of water placed in the conveyance system. This ratio is normally less than 1.0 for open channel conveyance systems, but it may be approximately 1.0 for pipeline conveyance systems.

Losses from open channel conveyance systems occur due to seepage, evaporation, and transpiration. These losses can be reduced by using lined channels and controlling vegetative growth. Some evaporation losses will be unavoidable.

Seepage and other losses are avoided in pressurized irrigation systems because leakage is minimal from well-designed and well-managed pipelines.

Irrigation application efficiency (E_a). Irrigation application efficiency is the ratio of the volume of irrigation water stored in the root zone and available for plant use (evapotranspiration) to the volume delivered from the irrigation system. This ratio is always less than 1.0 because of losses due to evaporation, wind drift, deep percolation, lateral seepage (interflow) and runoff which occur during irrigation.

Application efficiencies are also affected by those cultural practices that affect water storage in the plant root zone. For example, E_a is reduced by the use of plastic mulches which shed water from the production bed of some sprinkler irrigated field production systems, by nonuniform wetting of hydrophobic soils (soils which are resistant to wetting), and by plant root zones limited by containers in sprinkler irrigated container nursery production systems. The effects of site-specific factors such as these need to be evaluated to accurately determine application efficiencies of individual systems.

Application efficiencies are also affected by irrigation system management practices. Because it is not possible to measure and apply the exact amount of water required in the plant root zone at precisely the time that available soil water is depleted, excess water applications will sometimes occur. As a result, E_a will be reduced.

Typical and expected ranges of application efficiencies of irrigation systems are presented in Table 1 .

Irrigation Systems or Projects

Overall irrigation system efficiency (E_o). Overall irrigation efficiency is calculated by multiplying the efficiencies of the components. For a system which includes reservoir storage, water conveyance, and water application, the overall irrigation efficiency (Equation 1) is defined as:

$$E_o = (E_s) \times (E_c) \times (E_a) \quad (1)$$

where all terms are as previously defined

Equation 1 .

where all terms are as previously defined. Thus, the overall irrigation efficiency for a nursery irrigation system which is using water from an open reservoir with a 60% (0.60) storage efficiency, conveying it using an open channel from which 1/5 is lost in transit (0.80 or 80% conveyance efficiency), and which is using sprinkler irrigation, which is 25% (0.25) efficient, would be:

$$E_o = 0.60 \times 0.80 \times 0.25 = 0.12 \text{ or } 12\%$$

A system with this overall irrigation efficiency would need a reservoir that is designed to collect over 8 times the plant irrigation requirement because only 12% of the water collected in the reservoir would be effectively used.

As another example, if a grower has an irrigation system that pumps water from the Floridan aquifer rather than storing it ($E_s = 1.00$), conveys the water in a pipeline without leaks ($E_c = 1.00$), and applies it with a drip type of microirrigation system which has an application efficiency of 85% ($E_a = 0.85$), then the overall irrigation efficiency of this system would be:

$$E_o = 1.00 \times 1.00 \times 0.85 = 0.85 \text{ or } 85\%$$

This system would only need to pump 18% ($1.0/0.85 = 1.18$ or 118%) more water than the plant irrigation requirement because losses did not occur in storage or conveyance, and the application efficiency was high.

Effective irrigation efficiency (E_e). Effective irrigation efficiency is the overall irrigation efficiency corrected for water which (1) is reused, or (2) is restored to the water source without a reduction in water quality. Tailwater recovery systems allow runoff from an irrigated field to be recycled or used on another field. These systems increase E_e above E_o .

If irrigation water moves from the plant root zone due to lateral flow or deep percolation, its quality may be degraded by salts and other production associated chemicals. If this water cannot be intercepted for reuse in the same production system, then it is considered to be lost, reducing E_e . Thus, lateral flow and deep percolation will reduce irrigation efficiencies unless interceptor drains, ditches, or impermeable surfaces (in the container nursery) are installed to recover this water for reuse.

The effective irrigation efficiency (Equation 2) is defined as:

$$E_e = E_o + (FR) \times (1.0 - E_o) \quad (2)$$

where FR is the fraction of runoff, seepage, or deep percolation that is recovered. Losses due to evaporation, wind drift, and transpiration cannot be recovered.

Equation 2 .

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If, for example, an irrigator pumps from the Floridan aquifer ($E_s = 1.00$), conveys water in a pipeline ($E_c = 1.00$) and sprinkler irrigates a container nursery ($E_a = 0.25$), the overall irrigation efficiency would be:

$$E_o = 1.00 \times 1.00 \times 0.25 = 0.25 \text{ or } 25\%$$

If this grower installs a system to recycle runoff water and is thus able to recover 50% ($FR = 0.50$) of the water which was being lost from the system, the effective irrigation efficiency (from Equation 2) would be:

$$E_e = 0.25 + 0.50 \times (1.00 - 0.25) = 0.63 \text{ or } 63\%$$

Thus, the irrigation efficiency would be increased from 25% to 63% by recycling water which was previously being lost to runoff.

Irrigation Water Use Efficiency

There is no general agreement on a single definition of irrigation water use efficiency (E_u). E_u can be defined in two different ways.

E_u can be defined as the ratio of the volume of water beneficially used to the volume delivered from the irrigation system. Water that is beneficially used includes that which is applied for leaching of salts from the plant root zone, plant cooling, freeze protection, and other such uses, in addition to that stored in the plant root zone for evapotranspiration.

This definition of E_u is a true efficiency; that is, it is dimensionless and it expresses the ratio of two volumes of water. This ratio expresses the fraction of each unit of water delivered that is beneficially used.

As an example, excess water beyond that which can be stored in the plant root zone may be required to leach salts from the plant root zone if poor quality water is being used for irrigation. Since this would be a beneficial use, the irrigation water use efficiency would remain high, although the irrigation application efficiency would be reduced because all

of the water applied was not stored in the plant root zone.

E_u can also be defined as the ratio of the increase in production of the marketable plants to the volume of water applied by irrigation for irrigated as compared to nonirrigated production (Equation 3).

$$E_u = \frac{(Y_i - Y_o)}{V_i} \quad (3)$$

where

Y_i = marketable plants produced with irrigation,
 Y_o = marketable plants produced without irrigation,
 V_i = volume of irrigation water applied.

Equation 3 .

where

Y_i =marketable plants produced with irrigation,

Y_o =marketable plants produced without irrigation,

V_i =volume of irrigation water applied.

Although this definition of E_u is not a true efficiency, it has the advantage of expressing the increase in production from irrigation for economic evaluations of the profitability of proposed irrigation projects.

Because both of these definitions of irrigation water use efficiency are sometimes used, it is always necessary to clearly define E_u and to give its units when this efficiency term is used.

Factors Affecting Irrigation Efficiencies

Pressurized Irrigation Systems

Pressurized irrigation systems include sprinkler and microirrigation systems. Pressure is required for proper operation of the sprinklers and microirrigation emitters. These systems use pipelines to distribute water throughout the system.

Because networks of pressurized pipelines rather than soil hydraulic properties are used to distribute water, the field-scale uniformity of water application (and the associated irrigation application efficiency) is more strongly dependent on the hydraulic properties of the pipe network designed than site-specific soil hydraulic properties. Thus,

application efficiencies of well-designed and well managed pressurized irrigation systems are much less variable than application efficiencies of gravity flow irrigation systems, which depend heavily on soil hydraulic characteristics.

Sprinkler Irrigation Systems

During water applications, sprinkler irrigation systems lose water due to evaporation and wind drift. More water is lost during windy conditions than calm conditions. More is also lost during high evaporative demand periods (hot, dry days) than during low demand periods (cool, cloudy, humid days). Thus, sprinkler irrigation systems usually apply water more efficiently at night (and early mornings and late evenings) than during the day. Whether nursery growers can benefit from night-time irrigation depends on characteristics of their production systems. For example, some nursery plants may suffer from increased disease due to night-time irrigation, others may require irrigations more frequently than once per day or may require cooling by irrigation during peak water use periods of the day.

More water is lost by sprinklers that discharge water at high angles, over great distances, and at great heights above the ground surface because of greater opportunity time for evaporation. In addition, greater water losses occur from systems which discharge a greater proportion of small droplet sizes because small droplets are more readily carried by wind and they expose more surface area to the atmosphere for evaporation.

Some water is lost by interception on vegetative, soil, mulch, and other surfaces during irrigation. However, much of this intercepted water is not lost --rather it compensates for a portion of the plant transpiration by evaporating directly from the plant canopy and other surfaces, thus cooling the canopy. Application efficiencies will be reduced if water falls between widely spaced plants or outside the plant root zone, as in the cases of container nurseries.

Sprinkler irrigation application efficiencies are reduced by nonuniform water application. Nonuniform application causes some areas to be over-irrigated (and lose water and nutrients to deep

percolation) while other areas are under-irrigated (reducing plant growth). Thus, system design affects application efficiency. Nonuniform water application occurs when sprinklers are not properly selected or properly matched to the sprinkler spacing and operating pressure used. Nonuniformity also occurs if pressure losses within the irrigation system are excessive (due either to friction losses or elevation changes). Other causes of nonuniformity such as clogged nozzles or enlarged nozzles from abrasion by pumping sand also reduce application efficiencies.

Sprinkler water application patterns must overlap sufficiently (typically about 50%) to apply water uniformly. Because of this need for overlap, nonuniformity occurs at the edges of fields where overlap is not always possible.

It is not possible to apply water with perfect uniformity because of friction losses, elevation changes, manufacturing variation in components, and other factors. Also, achieving greater uniformities generally increases irrigation system cost because of the need for larger pipe sizes, pressure compensating emitters, or other considerations. State or national standards should be followed to achieve acceptable uniformities in irrigation system design. These standards balance the cost of wasted water and chemicals applied through irrigation systems against the irrigation system cost to achieve high uniformities.

Microirrigation Systems

Microirrigation systems are low pressure systems which distribute water through low flow rate emitters. Water is discharged near or within the root zone of the plants being irrigated. These systems include drip, line source, spray, microsprinkler, bubbler, and other similar types of systems.

Application efficiencies of microirrigation systems are typically high. Because these systems distribute water near or directly into the plant root zone, water losses due to wind drift and evaporation are typically small. Wind drift and evaporation losses can be high if spray or microsprinkler systems are operated under windy conditions on hot, dry days. Thus management to avoid these losses is important

to achieving high application efficiencies with these systems.

Primary losses in efficiency of micro systems occur from nonuniform water applications due to pressure losses from friction or elevation changes, or management problems such as over-irrigation or clogged emitters. As with other types of irrigation systems, design standards (resulting from economic considerations) require that water applications from micro systems be made at less than perfect uniformities, and this results in application efficiencies that are less than 100%.

Drip irrigation systems. Drip irrigation systems apply water in individual drops or small streams from individual drip emitters on, near, or below the soil surface. Application rates are typically in the range of 0.25-4 gph per emitter. The soil surface wetted is only that within 1-2 ft of the water source for typical Florida sandy soils. Wind does not affect these systems. Evaporation losses are also typically small because of the limited surface area wetted and the rapid surface drying and mulching of sandy soils.

Application efficiencies of drip systems are primarily dependent on the design hydraulics of these systems and on their maintenance and management. However, soil hydraulic properties influence water conveyance from drip emitters, thus also affecting application efficiencies, especially for young annual plants with immature root systems. Thus, system design, especially number of emitters per plant and the placement of emitters with respect to the plant root zone, influence application efficiencies. Application efficiencies are slightly greater for subsurface placement of emitters because the reduced wetting of the soil surface reduces soil evaporation losses.

Spray systems. Spray irrigation systems use low flow rate emitters to distribute water within a few feet around the emitter. In nurseries, they are used for large containers and field production of trees and shrubs. With these systems, water is typically applied at rates of 10-20 gallons per hour (gph) over a radius of 2-18 ft, from one emitter per tree. The popularity of these systems results from their ability to distribute water in a lateral direction and over a

significant fraction of the plant root zone and to provide a measure of freeze protection as compared to drip systems.

Because water is sprayed in very small droplets, some evaporation and wind drift losses may occur. Wind distortion of spray patterns may also occur. Thus, application efficiencies of these systems are typically less than those of drip or line source types of microirrigation systems, but E_a can be considerably less if these systems are operated on hot, dry, windy days.

Bubbler systems. Bubbler irrigation systems apply water into individual containers or basins around trees or other plants. Flow rates are higher than drip systems and thus clogging problems are avoided. In Florida, these systems are primarily used in nursery and landscaping applications because typical sandy soils limit large scale field applications. Bubbler system application efficiencies depend on the hydraulics of design, system management, and the effectiveness of the containers or basins in retaining water for use by the plant.

Potential Irrigation System Application Efficiencies

Potential irrigation system application efficiencies are application efficiencies that can be achieved with well-designed and well-managed irrigation systems. Potential application efficiencies must be known by irrigation system designers, managers, and water management personnel. Designers need to estimate how much water is lost in transmission, storage, and application, so that pumping systems and water supply systems can be adequately selected for specific applications. Irrigation system managers need to develop water budgets and irrigation schedules, both of which are partially based on the efficiency of water applications. Water management personnel need to know application efficiencies as one of the factors required to determine the proper amounts of water to be permitted for irrigation systems.

Irrigation system application efficiencies can vary widely, depending upon how well a system is designed and managed. Application efficiencies also vary with other factors, including stage of plant

development, time of year, and climatic conditions. However, average seasonal application efficiencies of well-designed systems that are scheduled to maintain adequate soil moisture levels to meet plant water requirements for evapotranspiration (ET) will be much less variable. The application efficiencies listed in Table 1 are believed by the authors of this publication to be reasonable values to be used for typical Florida conditions when irrigations are scheduled to meet plant water requirements for (ET). The values given are seasonal values which represent average nursery production conditions throughout the growing season.

Application efficiencies will be reduced from the values given in Table 1 if irrigation systems are operated to apply water for purposes other than maintaining adequate soil moisture for plant ET. As examples, application efficiencies will be reduced if water is applied for leaching of salts, freeze protection, establishment of young plants, plant cooling, or other beneficial uses. These water uses are reasonable and necessary for plant production, however, they are not all required for all production systems. Thus, irrigation water requirements for beneficial uses other than maintaining adequate soil moisture for plant ET must be determined on a case-by-case basis.

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Table 1.

Table 1. Pressurized irrigation system application efficiencies, E_a (%) ¹ .		
System type	Range	Average
Sprinkler irrigation systems		
Solid set systems - field production	70 - 80	75
For container nurseries	15 - 50	20
Microirrigation systems		
Drip or line source systems		
Surface	70 - 90	85
Subsurface	70 - 90	85
Spray systems	70 - 85	80
Bubbler systems	70 - 85	80
<p>¹Average seasonal irrigation system application efficiencies for well-designed Florida irrigation systems that are scheduled to maintain adequate soil moisture levels to meet plant water requirements for evapotranspiration (ET). Individual system application efficiencies will vary more widely as a function of stage of plant development, time of year, climatic conditions and other factors. Application efficiencies will be reduced from these values when water in addition to that required for plant ET is applied for leaching of salts, establishment of young plants, freeze protection, plant cooling, or other beneficial uses.</p>		