Efficiencies of Florida Agricultural Irrigation Systems [1]

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Irrigation efficiency is a measure of (1) the effectiveness of an irrigation system in delivering water to a crop, or (2) the effectiveness of irrigation in increasing crop yields. From definition (1), irrigation efficiency may be expressed as the ratio of the volume of water used or available for use in crop production to the volume pumped or delivered for use. From definition (2), irrigation efficiency may he expressed as the ratio of crop yield or increase in yield over nonirrigated production to the volume of irrigation water used. 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 crop 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 spray types of irrigation systems. However, evaporation during sprinkling cools the crop canopy, thus it reduces transpiration and partially compensates for evaporation losses.

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Surface runoff, subsurface flow from the irrigated area, canal seepage, percolation below the crop 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, crop, 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 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 dual production system

Estimates of irrigation efficiencies are also needed by water management personnel so that water needs can be estimated for management of the state's water resources.

Commonly used definitions of irrigation efficiencies, factors affecting irrigation efficiencies, and typical values for well-designed and well-managed Florida field-scale irrigation systems are presented in this publication.

Efficiency definitions

There are many meaningful definitions of efficiency which relate to irrigation and crop water use. In general. the term "irrigation efficiency" refers to the ratio of the volume of water delivered by an irrigation system to the volume that is input to the system. Irrigation efficiencies can be defined for components of irrigation systems, for entire field or farm-scale irrigation systems, as well as for multi-farm or regional irrigation projects.

The term "crop water use efficiency" normally refers to the ratio of crop yield to the volume of water used to produce the crop. 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 he 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.

In Florida, seepage losses to underlying soil formations and water tables occur through the sides and bottoms of earth structures. In high water table (flatwoods) locations, seepage may occur from the surrounding water table to a reservoir, adding water to the reservoir. In locations where water tables are deep, such as areas of northwest Florida where reservoirs are constructed to collect runoff water for future irrigation, seepage will cause losses from reservoirs.

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 from reservoirs occur whenever the water surface is exposed to the atmosphere. 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. Deep reservoirs have less surface area than shallow reservoirs that store the same volume. 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.

Reservoir losses and Es for Florida reservoirs vary widely, primarily due to the variable nature of seepage losses. In general, Florida reservoirs which are not recharged by seepage from a high water table should be designed to hold at least twice the anticipated water requirement for irrigation (Es = 0.50). However, site specific conditions may result in Es values that vary considerably from 0.50.

Water conveyance efficiency (E_e). 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. Open channels are used in south Florida where existing high water tables and restrictive soil layers minimize seepage losses. however, even under these conditions, Ec is very site-specific and must be determined by measurements taken at the site or estimated by persons experienced with these systems.

Pipelines are extensively used in Florida because large seepage losses occur from unlined channels constructed in deep sandy soils and because pressurized irrigation systems are extensively used. 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 crop 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 may occur during irrigation.

Application efficiencies are also affected by those cultural practices that affect water storage in the crop root zone. For example, Ea is reduced by the use of plastic mulches which shed water from the production bed of sprinkler-irrigated vegetable crop production systems, by nonuniform wetting of hydrophobic soils (soils which are resistant to wetting), and by crop 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 crop root zone at precisely the time that available soil water is depleted, excess water applications will sometimes occur. As a result, Ea will be reduced.

Typical and expected ranges of application efficiencies of Florida irrigation systems are discussed in detail in later sections of this publication.

Irrigation systems or projects

Overall (irrigation system, project or farm) irrigation efficiency (E_0). 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 is defined as E_0 =(Es) x (Ec) x (Ea) where all terms are as previously defined. Thus, the overall irrigation efficiency for an 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 the flood method of water application, which is 50% (0.50)efficient, would be E_0 =0.60 x 0.80 x 0.50=0.24 or 24%.

A system with this overall irrigation efficiency would need a reservoir that is designed to collect over 4 times the crop irrigation requirement because only 24% 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 (Es = 1.00), conveys the water in a pipeline without leaks (Ec = 1.00), and applies it with a drip type of microirrigation system which has an application efficiency of 85% (Ea = 0.85), then the overall irrigation efficiency of this system would be Eo = 1.00 x 1.00 x 0.85 = 0.85 or 85%

This system would only need to pump 18% (1.0/ 0.85 = 1.18 or 118%) more water than the crop 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 Ee above Eo. A citrus crown flood system, where water is drained from one block but used to irrigated the next block, is an example of a Florida production system where Ee is greater than Eo. Other examples include those watercress production systems where water is continuously recycled, seepage irrigation systems where tailwater is recycled from drainage ditches or ponds, and other systems such as sprinkler-irrigated strawberry and ornamental fern production systems where surface runoff or subsurface drainage is routed into ponds for reuse.

If seepage from open channels flows into the field being subirrigated, this flow will not be lost from the irrigation system. Thus, Ee will be greater than Eo.

If irrigation water moves from the crop 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 Ea and Eo. Thus, lateral flow and deep percolation will reduce irrigation efficiencies unless interceptor drains or ditches are installed to recover this water for reuse.

The effective irrigation efficiency is defined as Ee =Eo +(FR)x(1.0-Eo)

where FR is the fraction of the water lost that is recovered. Some of the water that leaves an irrigated field due to runoff, seepage, or deep percolation might be recovered in some cases. Losses due to evaporation, wind drift, and transpiration cannot be recovered.

If, for example, an irrigator pumps from the Floridan aquifer (Es = 1.00), conveys water in a pipeline (Ec = 1.00) and seepage irrigates potatoes and cabbage (Ea = 0.50) near Hastings, the overall irrigation efficiency would be E_0 = 1.00 x 1.00 x 0.50 = 0.50 or 50%

If this grower installs a system to recycle runoff water and is thus able to recover 40% (FR= 0.40) of the water which was being lost from the field (that is, approximately 40% of the water being lost was due to runoff), the effective irrigation efficiency (from Equation 2) would be Ee = 0.50+0.40 x (1.00-0.50) = 0.70 or 70%.Thus, the irrigation efficiency would be increased from 50% to 70% by recycling water which was previously being lost to runoff.

Crop water use efficiency

Crop water use efficiency is defined as the ratio of the mass of marketable yield or biomass produced per unit of water used. For this definition, crop use efficiency has units of production unit per water volume unit. Units typically used are ton acre-inch, pound acre-inch, or bushels/acre-inch in English units and kilograms) cubic meter in metric units.

This definition is not a true efficiency because it does not express a dimensionless ratio. It does, however, have the advantage of comparing both yield and water used, thus it is often used in economic comparisons of alternative crops.

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.

1. 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 crop root zone, crop cooling, freeze protection, and other such uses, in addition to that stored in the crop root zone for evapotranspiration.This definition E 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 crop root zone may be required to leach salts from the crop 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 crop root zone.

2. E_u can also be defined as the ratio of the increase in production of the marketable crop component to the volume of water applied by irrigation for irrigated as compared to nonirrigated production. $E=(y_i - y_o)/V_i$ where Y_i = mass of marketable crop produced with irrigation, Y_0 =mass of marketable crop 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. It is not meaningful if the crop cannot be produced without irrigation.

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 micro- irrigation 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 growers can benefit from night-time irrigation depends on characteristics of their production systems. For example, some crops may suffer from increased disease due to night-time irrigation, others may require rrigations 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 crop root zone, as in the cases of container nurseries or young citrus production systems, or water which is shed away from the crop root zone as in the case of plastic mulched bed production systems.

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 crop yields). Thus, system design affects application efficiency. Nonuniform water application occurs when sprinklers are not properly selected nor 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.

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.

Solid set sprinkler systems. Properly designed solid set systems have sprinklers permanently installed at spacings that result in optimum uniformity. However, wind, incorrect operating pressure, and component wear or failure can still distort application patterns and reduce uniformity and application efficiency.

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 possible. This effect is less significant for large fields and fields shaped so that the perimeter is minimized with respect to the total land area. Thus, large square or rectangular fields are less affected by this problem than small oddshaped fields. Part-circle sprinklers can be used at the edges of fields to improve uniformity, but they are more mechanically complicated and more expensive than full-circle sprinklers. Because of their mechanical complexities, part-circle sprinklers fail more frequently under field conditions. Thus part-circle sprinklers are not commonly used in large scale field irrigation systems.

Gun sprinkler systems. Gun sprinklers are large sprinklers that discharge high flow rates at high pressures. Because water is sprayed over greater distances, at greater heights, and at greater velocities, greater amounts of water are typically lost to wind drift and evaporation than from solid set systems.

Portable guns irrigate circular land areas. They are moved from location to location, usually with some overlap of the previously irrigated area. Because of nonuniform water applications where patterns overlap, and because of the greater wind drift and evaporation losses, portable guns typically have lower application efficiencies than solid set systems.

Traveling guns are self-propelled. They move slowly across the field, irrigating rectangular strips of land. This continual motion compensates for nonuniformity in the application pattern in the direction of travel, resulting in greater uniformity in the direction of travel than between the irrigated strips. Because of insufficient overlap at startup and at the end of a length of run, water is applied more efficiently for long lengths of run than for short run lengths. Traveling guns typically have greater application efficiencies than portable guns because of the greater uniformity that occurs in the direction of travel.

Center pivot and lateral move systems. Center pivot and lateral move irrigation systems are self-propelled multiple sprinkler systems which are designed for a specific location. Overlap of sprinkler patterns and uniformity of water application are generally not problems except at field boundaries. Large changes in elevation which affect system pressures, or large changes in soil properties which affect infiltration rates and soil water storage may also lower water application efficiency and uniformity. Center pivot or lateral move systems which use gun sprinklers on the ends of the laterals to expand the irrigated area will have lower overall application efficiencies because of the greater water losses from the guns.

In recent years, center pivot and lateral move systems have been developed which operate at low pressure and apply water either with controlled droplet sizes or by dripping near the surface so that application efficiencies are high, even under moderately windy conditions. These systems are generally limited in application to soils with high infiltration rates such as typical Florida sandy soils. These systems may have application efficiencies equal to or better than those of solid set irrigation systems.

Periodic move lateral systems. Periodic move lateral systems include hand-move or portable, end-tow, side-move, and side-roll systems. Each of these four types of systems functions similarly from the standpoint of water application each consists of a lateral pipe with sprinklers located along its length. The different classifications refer to the way that the sprinkler laterals are moved.

Hand-move or portable sprinkler systems are moved manually between irrigations by disassembling sections of aluminum lateral pipe and carrying them to the next location. End-tow systems are typically skid-mounted, and they are moved by towing them from the end of the lateral with a tractor. Side-move and side-roll systems are laterals mounted on wheels. Between irrigations, these systems are manually or automatically rolled in a lateral direction to the new location.

Periodic move lateral systems. Periodic move lateral systems are designed to apply water uniformly along the laterals. Nonuniform applications and lower application efficiencies occur when the laterals are not properly positioned between settings. Nonuniformity also occurs at the ends of the laterals where sprinkler overlap is not adequate. Thus, long laterals may apply water more uniformly and efficiently than short laterals if field slope and soil properties do not affect applications.

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 crop 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 crop 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 and line source systems. Drip irrigation systems apply water in individual drops or small streams from individual drip emitters on, near, or below the soil surface. Line source systems apply water from closely spaced orifices or by continuous seepage along the lateral pipe length.

Application rates are typically in the range of 0.25-4 gph per emitter or 0.3-2.0 gpm per 100 ft of lateral length. 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 and line source systems are primarily dependent on hydraulics of design 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 stems. 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. By far the most common application in Florida is that of under-tree microirrigation systems for citrus. With these systems, water is typically applied at rates of 10-20 gallons per hour (gph) over a radius of 8-18 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 crop 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 Ea 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.

Gravity flow irrigation Systems

Gravity flow irrigation systems include subirrigation (seepage) and surface irrigation systems. These systems distribute water by flow through the soil profile or over the soil surface.

Because water is distributed by gravity flow, the uniformity of water application (and the associated irrigation application efficiency) is strongly dependent on the soil topography and hydraulic properties. Growers typically use precision land grading practices to minimize the effects of topography. however, soil characteristics are not readily changed, and losses of irrigation water due to lateral flow is highly dependent on the soil water status on surrounding land areas at the time that irrigation is practiced. As a result of these site-specific factors, water application efficiencies of gravity irrigation systems may vary widely in space and time, and they are very site-specific.

Subirrigation (seepage) systems

Subirrigation or seepage irrigation systems irrigate by water table management. A water table is established above an existing water table or above a restrictive soil layer by pumping water into open ditches or underground conduits. Not all of the water pumped is available for crop use depending on the depth to the natural water table, large quantities may be required to build and maintain the water table, and this reduces the application efficiency. Other losses occur due to deep percolation below the crop root zone and to subsurface lateral flow to surrounding areas.

The magnitudes of losses by both of these mechanisms are site- and time-specific as they depend on the permeability of restrictive soil layers and the management practices occurring in surrounding fields. Thus, irrigation application efficiencies for these types of systems can vary widely, depending upon site-specific conditions.

Two types of seepage irrigation systems, classified by method of water application, are used in Florida. Surface ditch systems use field ditches which are called water furrows or lateral ditches. Subsurface systems use underground pipes or mole drains to control water tables. The underground pipes are slotted plastic pipes that are typically used for subsurface drainage.

Florida's humid climate requires drainage on high water table soils, and field slope is necessary for surface drainage. Surface runoff normally occurs from surface ditch systems because of field slope. Runoff reduces irrigation application efficiencies unless this water is recycled.

The use of subsurface irrigation systems allows water to be applied and water tables to be controlled without surface runoff. However, in many areas of the state, water quality problems prohibit the use of underground pipes because of clogging.

Water distribution from seepage irrigation systems occurs below the soil surface. Therefore, wind and other climatic factors do net affect the uniformity of water application. Also, evaporation losses from both surface ditch systems and underground pipes are about equal because the soil surface is wet and evaporation occurs at near potential rates with both systems.

Conveyance efficiencies are affected by the system design. In open ditch systems, water is conveyed from the pump or other water source to the lateral ditches in open ditches. In semi-closed systems, water is conveyed by pipe from the water source to a header or manifold pipe which individually distributes water to the open field ditches.

Conveyance losses of open ditch Systems depend on the hydraulic properties of the soil in which the ditch is constructed, the height of surrounding water tables, and the location of the water source with respect to the irrigated field. Losses may be very significant when water is conveyed long distances through nonirrigated areas. Conversely, conveyance losses may be negligible if the water source is a well in the center of the field being irrigated and seepage from the ditch flows into the field being irrigated. Conveyance losses are avoided in semi-closed systems where the water is contained in a pipeline.

Surface (flood) irrigation Systems

Surface irrigation systems are those in which water is distributed by flow across the soil surface due to either soil slope or slope of the water surface. Two types of systems exist. In the first, water tables are not established-rather, the soil hydraulic properties restrict water movement through the soil to low rates. These soil properties allow water to be distributed across the surface before significant deep percolation losses occur. This type of system is thus limited to "heavy" soils with low hydraulic conductivities such as barns, clay barns, and clays. This type of system is not used in Florida because the typical Florida agricultural soil is sandy with high hydraulic conductivity. The heavier Florida soils are generally not irrigated for agricultural purposes because their high waterholding capacities can store much of the large annual rainfall.

A second type of surface irrigation system is flood irrigation. Two types of flood irrigation systems, crown flood (for citrus production) and continuous (paddy) flood (for rice production) are used in Florida Flood irrigation is practiced only on flatwoods soils with shallow restrictive soil layers or high natural water tables.

Crown flood systems. Crown flood systems are used to irrigate citrus in some areas of Florida. This is practiced only on bedded citrus groves on flatwoods soils. With this system, water furrows are filled with enough water to cause the water level to rise to the tree trunks (crowns) on the beds. Water is left in the water furrows for a few hours up to 2 days so that it can move into the soil beds. The field ditches are then drained.

Application efficiencies of crown flood systems greatly depend on the soil hydraulic characteristics, permeability of restrictive layers, water table levels, and the characteristics of surrounding land areas. Application efficiencies are significantly increased if the excess irrigation water drained from the citrus groves is reused. If drainage water is reused, the application efficiency has been observed to be high (75%), while if the excess water is lost, then the application efficiency has been observed to be low (25%).

Continuous flood (paddy) systems. Rice production systems are continuously flooded. This irrigation practice involves establishing and maintaining a water table above the soil surface. Again, as for subirrigation and crown flood irrigation systems, site-specific characteristics strongly impact irrigation application efficiencies. The value of Ea will vary as a function of the soil hydraulic characteristics and water table characteristics of surrounding land areas.

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 crop 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 crop water requirements for evapotranspiration (ET) will be much less variable. The application efficiencies listed in Tables 1 and 2 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 crop water requirements for (ET). The values given are seasonal values which represent average production conditions throughout the growing season.

Application efficiencies will be reduced from the values given in Table 1 and Table 2 if irrigation systems are operated to apply water for purposes other than maintaining adequate soil moisture for crop ET. As examples, application efficiencies will be reduced if water is applied for leaching of salts, freeze protection, establishment of young plants, crop cooling, or other beneficial uses. These water uses are reasonable and necessary for crop 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 crop ET must be determined on a case-by-case basis.

Because uniformity of water application of gravity irrigation systems is strongly influenced by soil hydraulic properties, application efficiencies of gravity flow irrigation systems range much more widely than those of pressurized irrigation systems. Average values are not estimated in Table 2 because gravity flow system application efficiencies are very site-specific.

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Table 1.

Table 1. Pressurized Irrigation system application efficiencies, Ea (%)[2]

Sprinkler irrigation systems

System Type	Range	Average
Solid set systems	70-80	75
For container nurseries	15-50	20
Guns		
Portable guns	60-70	65
Traveling guns	65-75	70
Center pivot and lateral move systems	70-85	75
Periodic move lateral	65-75	70
Hand-move or portable laterals		
End-tow systems		
Side-roll system		
Side-move systems		
Microirrigation systems		
Drip or line source systems		
Surface	70-90	85

Table 1.

Subsurface	70-90	85
Spray systems	70-85	80
Bubbler systems	70-85	80

2. Average seasonal irrigation system application efficiencies for well-designed Florida irrigation systems that are scheduled to maintain adequate soil moisture levels to meet crop water requirements for evapotranspiration (ET). Individual irrigation application efficiencies will vary more widely as a function of stage of crop 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 crop ET is applied for leaching of salts, establishment of young plants, freeze protection, crop cooling, or other beneficial uses.

Table 2.

Table 2. Gravity flow irrigation system application efficiencies, E_a (%)[3]

Subirrigation (see page systems)

System type	Range
Open field ditch systems	
Open ditch conveyance systems	
Flow through	20-70
Tailwater recycle	30-80
Semi-closed conveyance	
Flow through	30-70
Tailwater recycle	40-80
Subsurface conduit systems	40-80
Surface (flood) systems	
Crown flood systems	25-75
Continuous flood (paddy) systems	25-75

3. Average seasonal irrigation system application efficiecies for well-designed and well-managed gravity flow irrigation systems in Florida. Average values are not estimated because application efficiencies are site-specific and range widely for gravity flow systems. Individual irrigation application efficiencies will vary more widely as a function of stage of crop development, time of year, climatic conditions and other factors. Application efficiencies will be reduced from these values when irrigation water is applied for other beneficial uses such as freeze protection.