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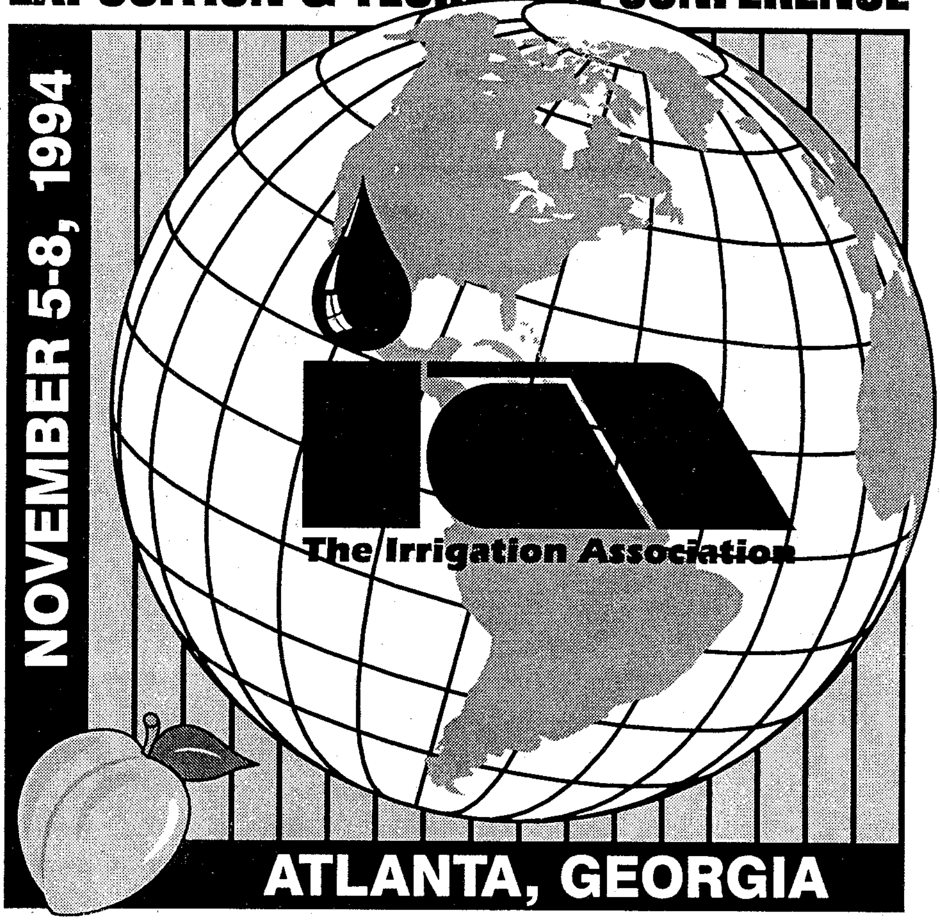

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PROCEEDINGS

IRRIGATION AND SUBIRRIGATION IN THE SOUTHEASTERN U.S.[1]

James L. Fouss and Carl R. Camp[2]

Background and Introduction

Irrigation in humid areas, such as the southeastern U.S., is governed by the same principles and technologies as in more arid areas, but differences in climate, soils, and prevalent crop culture require considerations of additional factors in the design and management of irrigation systems. Humid regions are defined as those areas with normal annual rainfall approaching or exceeding annual evapotranspiration (E_t). Aside from the obvious difference in rainfall, climate in humid regions may be unique in several other ways, many of which are caused by the higher humidity associated with more available water. Cloudiness reduces total solar irradiance, and the cloud type, typically cumulus, causes high variability in irradiance on a short-time scale. Dew forms frequently, and wet leaf conditions may continue for several hours after sunrise. July climatic conditions in the southeastern U.S. include mean temperatures of 27-30°C, mean daily irradiance of 20-25 MJ/(m^2.d), mean wind of 10-15 km/h, and mean relative humidity of 75-80%. The high humidity and low wind speeds often result in crop canopy temperatures above the air temperature until late in the day. One further climatic characteristic of the southeastern U.S. is the mean freeze-free period of greater-than or equal-to 210 days, which allows long-season cultivars and double cropping as a normal practice. The transition at the beginning and end of the annual growing season is poorly defined. Significant periods in both the spring and fall have days warm enough to cause considerable crop growth but with a significant likelihood of night-time frost or freeze. These combinations of length and vague limits to the growing season complicate water management for both frost/freeze protection and multiple cropping in the Southeast (Camp et al. 1990).

Soils in the southeastern U.S. vary across the total range of textural classes in much the same manner as other regions. Spatial uniformity of soil properties can be very poor, particularly in areas where topography changes within short distances. Poor soil spatial uniformity, particularly for soil properties such as water storage capacity, severely complicates irrigation management. In many cases, soil properties change drastically within the area covered by a small center pivot system. A research study that investigated crop yield for 12 crops during a 9-year period in the southeastern Coastal Plain found there was almost as much variation within soil mapping units as among mapping units, that statistical regression and mechanistic modelling were not successful in explaining causes for these differences, and geostatistical

[1] Contribution of the USDA, Agricultural Research Service, Natural Resources and Systems, Water Quality/Water Management Research Units, in the Mid South and South Atlantic.

[2] James L. Fouss, Agricultural Engineer and Lead Scientist, USDA-ARS, Soil and Water Research Unit, Baton Rouge, LA; Carl R. Camp, Jr., Agricultural Engineer and Lead Scientist, USDA-ARS, Coastal Plains Soil, Water, and Plant Research Center, Florence, SC.

analysis could only describe patterns (Sadler et al. 1994). The landscape is extremely variable, ranging from wet, low-lying areas with persistent high water tables to relatively high ground surface elevations, with steep slopes and little groundwater at shallow depths. These variations result from the combined effects of geology, topography, and climate. Soil variability and small cropped areas bounded by trees combine to cause extremely variable soil water storage and E_t rates within the same field.

For agricultural cropland in humid areas with normally shallow water table conditions, soil-water management by water table control methods is often feasible. Management or control of the shallow groundwater in such areas is difficult, however, because of the erratic spatial and temporal distribution of rainfall. Periods of excess and deficit soil water conditions often occur during the same cropping season. Thus, both drainage and irrigation facilities are needed to maintain soil-water content in the root-zone within the optimum range for crop production. Drainage has traditionally been considered separately from irrigation and other water control practices. These practices should be considered together in total water management systems for agriculture. A total water management system that includes surface drainage, plus water table control (WTC) via dual purpose subsurface conduits is becoming popular in humid areas. These systems may involve subirrigation, where water is pumped in from an external source to maintain a relatively constant water level at the drainage outlet that is above the normal subsurface drain elevation (depth), or controlled-drainage, where no water is added, except that infiltrated from rainfall, but the water level at the drain outlet must exceed a set elevation (e.g., a weir structure) before it can discharge from the system. Tens of thousands of hectares of these systems have been installed in the Carolinas, the Midwest, and Quebec in Canada during the last decade (Fouss et al. 1990).

Generally, pests such as insects, nematodes, fungal and bacterial pathogens, and weeds are more plentiful in humid regions such as the Southeast. Increased rainfall supports more plant biomass, and mild winter temperatures allow a diversity of living vegetation to exist year-round, both on cropped and border areas. In addition to exacerbating weed problems, the living vegetation serves as primary and secondary hosts of insects, nematodes, and diseases. In much of the region, the soil does not freeze significantly, and winter is a time of moist soil conditions. Thus, while freezing or desiccation may reduce pathogen populations in other regions, pathogens are supported over winter in humid areas. Rapid and abundant vegetative growth and prevalence of non-cropped borders, even in prime agricultural areas, make this difficult. Existence of diseases associated with high humidity, wet plant surfaces, and periods of wet soil conditions generally reduce the potential number of crops that can be grown in humid areas as compared to arid areas (Camp et al. 1990).

In the future it will become increasingly important that water management practices on agricultural cropland be integrated with fertility and pest management practices (i.e., agrochemical applications) so that losses of agrochemicals in runoff and subsurface drainage flows are minimized to reduce the risk of environmental pollution. Extensive research is being conducted in the southeastern U.S. to develop new technology for integrating water-fertilizer-pesticide management systems (Willis, et al. 1990, 1992).

Irrigation in the Southeastern U.S.

Most of the same types of irrigation systems used in other areas are used in the southeastern U.S. The size and mix of these systems depend upon soil type, field size and shape, topography, crop, and availability of adequate water supplies and may be somewhat different than in other areas. For example, center pivot irrigation systems in this area may vary in size from 5 hectares to more than 100 hectares.

In the southeastern U. S., the predominant system types are sprinkler, microirrigation and water table management systems. However, in parts of Florida, Louisiana, Arkansas, and Mississippi large areas are surface or gravity irrigated. Rice and agronomic crops such as cotton, soybean, and corn are produced in large areas of Arkansas, Mississippi, and Louisiana, while citrus and vegetables are produced in large areas of Florida. The extent of irrigation and water management practices in the southeastern U.S., categorized as Sprinkler, Low-Flow, or Gravity Systems (with major sub-categories), are illustrated by the survey data given in Table 1.

Table 1. Irrigation and water table control (controlled-drainage/subirrigation) in the southeastern U.S. (in thousand hectares)*

State	Sprinkler			Low Flow			Gravity		
	Total	Trav-eller	CtrPvt Linear	Total	Drip	Perf. Pipe	Total	Surface	CD or SI
Ala.	60	22	34	5	0	0	0	0	0
Ark.	83	2	79	2	2	0	1164	0	0
Fla.	254	73	63	173	25	0	398	36	362
Ga.	493	132	328	28	27	0	†	0	0
La.	87	6	76	1	1	†	266	266	0
Miss.	164	10	152	1	1	0	323	0	0
N.C.	79	34	13	4	2	1	103	103	89
S.C.	57	20	25	5	4	1	†	†	0
Tenn.	15	6	5	2	0	0	2	2	0
Total	1293	304	776	221	61	2	2257	408	451

* Source: Irrigation Journal 44(1):26-41, 1994. † Less than 100 hectares

Sprinkler and microirrigation systems -- Traveller systems are more important in the Southeastern U.S. than in most other areas, especially the arid and semi-arid areas, because of the smaller size and irregular shape of irrigated fields, fields not being located contiguously, variable crop type, soil spatial variability, and dispersed water supplies. The choice of sprinkler system type to use is often complex and depends upon many factors. Because of rainfall, irrigation provides a lower marginal return than in arid or semi-arid areas; consequently, growers must consider whether income increase and risk reduction are sufficient to cover capital investment and annual operating cost. Another concern is whether changing to irrigated agriculture will require major changes in the farming operation, management, and equipment.

The land area of crops being irrigated with microirrigation systems, which include various in-line emitters, tapes, discrete emitters, and micro-sprinklers, increases each year. Fruits, vegetables, and, to a lesser extent, nursery and greenhouse crops are the major crops being irrigated with these systems. Line-source microirrigation systems are being used mainly to irrigate vegetable crops, either with or without plastic mulches. Most of these use laterals buried 2-4 cm under the soil surface. Point-source microirrigation systems are being used to irrigate vine, bush, and tree crops and both container and field-grown nursery crops. Micro-sprinkler systems are mainly used to irrigate container, shrubbery, vine, bush, and tree crops. There has been little use of subsurface microirrigation systems on field crops in humid areas, but recent research results indicate that a useful system life of at least 10 years is probable and that crop yields are not reduced for wider lateral spacings (2 m), which greatly increases the feasibility of subsurface microirrigation for agronomic crops (Camp et al. 1993a,b). A schematic diagram of subsurface microirrigation for two lateral spacings is shown in Fig. 1.

Some sprinkler systems have been used in combination with water table control where a structure in a channel controls the stream level, reducing outflow of shallow ground water, and maintains the field water table about 1 m below the soil surface. Because topography and soil characteristics prevent subirrigation (drain lines or field ditches) from supplying sufficient water in some areas, sprinkler irrigation systems are used to apply irrigation to the soil surface. The channel and shallow ground water provide a source for both sprinkler irrigation and direct uptake by crops from the water table (Doty et al.1987).

Water Table Control (WTC) Systems -- Water table control via controlled-drainage and subirrigation is not new. It has been practiced for many years in scattered locations, such as in Florida in both the sandy flatwoods soils and the organic soils near the Everglades; in the organic soils of the Great Lake States of Michigan, Indiana, Ohio, and Minnesota; and in the Sacramento-San Joaquin Delta in Central California (Fouss et al. 1990).

Some of these applications date back to the 1920's . While several hundred thousand hectares were involved, most of the early applications were on very permeable organic or sandy soils. Ditch or subsurface drain spacings were relatively wide (e.g., 30 m or greater) and the water tables responded quickly to raising or lowering drain water levels. Feasibility studies in the 1970's showed that water table control practices could be applied on finer textured soils by fitting the drain spacing and other design parameters to soils and site conditions. Computer programs to simulate the performance of the system were developed and applied for design and operation. Finally, several studies have shown that controlled-drainage can be used to conserve water and significantly reduce pollutant loads from drained agricultural lands (Fouss et al. 1990).

Controlled-drainage permits storage of water in the soil profile by raising the water level in the drainage outlet through the use of an adjustable weir overflow pipe. "Free" drainage to the full depth of the subsurface drains is often needed during rainy periods to reduce the duration of excess soil-water conditions in the root-zone. During subirrigation, the water level at the drain outlet is maintained just below the water table control structure overflow elevation by pumping water from an external source. In coastal areas of the South and Southeast, where gravity flow outlets are often not possible or practical, WTC systems are commonly connected to sumps in which the water level is controlled by pumps rather than an overflow or gravity flow outlet. Water is pumped out of the sumps for drainage and into them for subirrigation. A schematic diagram illustrating an automatic water level control sump in the subirrigation mode is shown in Fig. 2. One of the most troublesome aspects of designing or operating such systems is preventing randomly occurring periods of wet weather from causing crop injury because of excessive soil-water conditions, when the water level at the outlet is being held high for subirrigation purposes. Timely control of the system is a major problem for farmers who try to manage such systems manually, and for designers of controller units to automatically adjust or regulate the outlet water level. Such timing is especially acute in fine textured soils where the small drainable porosity, combined with frequent rainfall events can cause rapid and large variations in water table depth. The problem is less severe in coarser textured soils where the water table is easier to manage and where the overflow or outlet water level may remain constant for most of the season.

An integrated design for a WTC system includes development of the field installation plan and a recommended method of operation or management. The system design should permit control of the water table (WT) depth over the range needed for the cultural practices to be followed and the crops to be grown. The overall goal is to manage and utilize the shallow groundwater in the soil profile as a source of water for crop production. That is, the WT must be maintained shallow enough for crop roots to obtain water from the shallow groundwater (WT) and/or by upward flux of water from the WT to the root-zone. Specific design and operational objectives for WTC systems can vary with soil, crop, climate, and topographic conditions, but the following generally apply to most systems designed for the humid region:

1. To provide trafficable or workable conditions so that farming operations, such as seedbed preparation, tillage, harvesting, etc., can be conducted in a timely fashion;
2. to reduce crop stresses caused by excessive soil-water conditions;
3. to reduce or eliminate stresses caused by deficit soil-water conditions;
4. to minimize harmful off-site environmental impacts;
5. to conserve water supplied by precipitation, minimizing subirrigation water requirements; and
6. to control salinity and alkalinity, where applicable.

Irrigation Management in the Southeastern U.S.

It is imperative that the irrigation manager select a management objective before the growing season because many cultural practices are different for irrigated culture than for rainfed culture. For example, if fertilizer and seeding rates, cultivar, and row spacing recommended for irrigated conditions are not used, the maximum benefit of irrigation will probably not be realized and profit could be reduced. Historically, cultural practices for crops in this area have been selected to produce an acceptable crop yield with below or near "normal" rainfall. Even when irrigation was first used in this area, it was used only to supplement rainfall during periods of drought. Because of the high labor costs of those early hand-move systems, a significant threshold had to be overcome before irrigation was initiated each season. There was a great tendency to "wait another day" in anticipation of rainfall. Regardless of the particular objective selected, irrigation must be managed as an integral part of the production system, not as an element to be used only in emergency or unusual situations. Four possible management objectives include maximum profit, maximum yield, minimum risk, and resource optimization.

Maximum profit is probably the most popular objective, primarily because of the realization that, with increased operating costs, maximum yield does not necessarily provide maximum profit. As markets become more competitive, commodity prices tend to decrease, and this objective becomes more important. The maximum yield objective lost favor as energy and other operating costs increased and commodity prices decreased. Also, this management objective is often not compatible with conservation of water and energy resources and with protection of surface and ground water. The minimum risk objective may be desirable for a variety of situations where the manager is required to reduce exposure or vulnerability in certain areas, e.g. high debt level, low cash flow, marginal system reliability, and commodity delivery contract. Finally, it may be necessary to adopt an objective based on optimization of available resources, specifically water, energy, land, and/or equipment. Some irrigation systems and water supplies in the southeastern U.S. are designed for normal or average climatic conditions and may be unable to provide irrigation sufficient for optimum crop growth and yield during extreme events (high E_t and low rainfall). It may become necessary to allocate water to those crops that would benefit most from irrigation; hence, alternatives, such as less-than-optimum irrigation for several crops or optimum irrigation for some crops and little or none for others, have to be considered.

Most available irrigation scheduling methods can be used as well in this area as in other climatic areas, although some adaptation and additional interpretation and experience may be required. Although irrigation scheduling technology for humid areas such as the southeastern U. S. has been available for several years, it is not widely used in the Southeast. Major factors that determine the acceptability of any irrigation scheduling method are ease of use, maintenance requirement, user confidence, and expense.

The major difference in scheduling irrigation in this area, in comparison to arid areas, is the increased need to deal with rainfall, either to benefit from it by using rainfall to reduce the irrigation requirement or to minimize adverse crop conditions such as saturated soils caused by rainfall following irrigation. For this reason, irrigation scheduling methods that utilize some type of weather data (forecasts, long-term record, generated, etc.) to project the need for irrigation, normally for a specified probability, for several days ahead will be most effective in humid areas. Various computer-based methods, such as those using a water balance or crop simulation, could be adapted to include this capability, if it is not implemented in current versions. The major disadvantage in computer-based scheduling programs is the need for accurate input (soil, crop, and climate) data and little reliable data of this type exist for this area, particularly crop water use rates. The extreme spatial variability of soils also causes problems in applying these techniques because a single set of soil parameters normally must be selected for each irrigation system which may include several different soils. Finally, a computer-based water balance or crop simulation model must accurately represent the field situation under a wide range of conditions. Most currently available water balance methods provide reasonably accurate results for short time periods; therefore, they require periodic correction during the growing season (Camp et al. 1990).

Various forms of computer-based water balance scheduling methods have been developed and evaluated for humid-area conditions. A simple water balance method that was developed for the personal computer and used the modified Jensen-Haise method to estimate daily E_t was evaluated for corn over a large geographic area within the southeastern USA for a three-year period ending in 1982 (Camp et al. 1990). At each of the five locations, the computer-based water balance method was compared to a method using tensiometers. At a sixth location, another computer-based procedure was used and was evaluated using measured soil water contents. These results showed only small, inconsistent differences between scheduling methods among the various locations, established the usefulness of the computer-based water balance as a scheduling method, and demonstrated the importance of accurate soil and water input parameters as well as the need for periodic corrections during the growing season. At one location in this study, a method using pan evaporation was included in the comparison with other methods. However, no consistent differences were evident during this three-year study, which included soybean as well as corn. Other computer-based procedures which can be used to schedule irrigation include calculated risk models while others, which were not developed to schedule irrigation, may be used to effectively assist in analysis of irrigation applications (Camp et al. 1990).

Plant growth simulation models, expert systems, and irrigation system design and management models have been developed and refined by several research groups. DRAINMOD, a drainage and subirrigation design and operation model for drainage-subirrigation systems, is probably the best known and most accepted water management model in humid areas. For soybean, SOYGRO has been widely studied and has been adapted to irrigation scheduling. Similarly the cotton model GOSSYM has been widely examined under pilot studies and used by farmers, especially in the Southeast. The CERES models for wheat and maize have also been evaluated and used on a limited scale in the eastern US. Improvements in these and related models will lead to increased acceptance of simulation models for estimation of crop water requirements and use in scheduling irrigation. Expert systems have been devised to simplify data input, model operation, and interpretation of predictions made by the crop models. These, as well as automated weather stations, should also hasten acceptance of models. Factors hindering use of the models in humid climates include poorly characterized or extremely variable soil, lack of centralized updating of models, and lack of on-site rain gauges needed for this variable rainfall area (Camp et al. 1990).

Scheduling methods that are based upon soil or plant measurements, basically, are "reactive" management tools in that first, an observation is made, then the value is compared to a preselected threshold value that indicates when irrigation is required, and finally a decision is made either to irrigate or not to irrigate. The procedure can be modified depending upon the knowledge level of the manager, particularly with respect to the probability of receiving rainfall within a specified period of time. This information can then be incorporated with the measured value to influence the decision of whether to irrigate or not.

Sensors and systems to assist in irrigation scheduling or to automatically control irrigation application that are available for general use can be used in humid areas although some may require modification and others may require special interpretation or may be limited in their scope of application. Soil-based methods for sensing need for irrigation include tensiometers, gravimetric sampling, neutron probes, moisture blocks, and simple manual estimation. General limitations to these methods may assume greater importance in the Southeast. For instance, stratified soils with very distinct horizon-to-horizon texture changes make measurement of soil water content using neutron probes less satisfactory than in uniform soils. The relatively small changes between upper and lower limits of available water in sandy soils also render the neutron probe less satisfactory. The rate of increase of tensiometer readings in sandy soils reduces the usefulness of this method for these conditions, and tensiometers often require frequent servicing. High soil variability requires increased spatial resolution in sampling, with associated increased labor requirement. The use of soil-based methods for scheduling irrigation does eliminate the need for estimating E_t as well as other soil and climatic parameters required for computer-based methods. One must develop a certain amount of experience with soil-based techniques, however, to practice predictive irrigation management. By using soil-base measurements for re-initializing the soil water contents in computer-based water balance methods, the benefits of both techniques can be obtained.

Because of variable irradiance or a shift in canopy-air temperature differences (T_c-T_a) in the southeastern U. S., the use of canopy-temperature-based crop water status indicators, such as the crop water stress index, or CWSI may require modification before use. Irrigation management using a technique that was developed under nearly constant clear-sky conditions would appear to be susceptible to error under humid conditions, although commercial units are being offered and used. It appears that locally-calibrated coefficients for the empirical CWSI should be used in humid areas. The theoretical CWSI may allow accounting for differences in irradiance and windspeed Any empirical method, including E_t models, should be used with caution outside the range of validation (Camp et al. 1990).

Miscellaneous Irrigation Benefits/Functions

Chemigation may be especially well suited for humid areas. Frequent low-volume irrigations, often practiced in humid areas, permit chemigation with little change in irrigation schedules. Risk of rainfall following irrigation increases risk of nutrient leaching so that frequent applications of small amounts of chemicals through chemigation should reduce the risk of leaching. Reducing leaching is important for efficiency of the enterprise and for maintaining quality of ground water, both of which are assuming greater significance in humid as well as other areas. The numerous weed, insect, and disease pests prevalent in this area require postplant control for which chemigation is well suited. Because frequent rainfall reduces the need for irrigation, a system design capable of minimum water applications is required to prevent water logging and leaching. Of the major types of chemigation, fertigation is the most common. For this, center pivot, linear move, solid-set sprinkler, and microirrigation systems are normally used, because they provide the best uniformity.

Frost/freeze protection is particularly important for some crops because warm temperatures occur much earlier than the probable last frost or freeze. Warm temperatures induce budding and blossoming, particularly in tree and small fruit crops, and late frost can cause severe economic damage. Most frost/freeze protection is accomplished with overhead sprinkler irrigation for crops such as citrus, apple, peach, and other tree fruits; small bush crops such as blueberries and strawberries; some vegetables and nursery crops; and seedling beds.

Although humid-area rainfall is often sufficient for crop establishment, irrigation can ensure uniform germination and emergence. For this purpose most sprinkler systems are well adapted. Travellers with high-volume (gun) sprinklers produce larger droplet sizes and may cause surface sealing and poor germination. Furrow irrigation, subirrigation, and some microirrigation systems are not well suited for this purpose because of inadequate moisture movement to the seed location. Microirrigation systems can be used effectively for establishing transplanted crops, such as trees and vine crops. Microirrigation has also been used to increase quality of crops for which economic yield is highly sensitive to quality, e.g. grapes and vegetables.

Leaf and fruit temperatures that exceed air temperature by 6-7°C are not uncommon in this area. Sprinkler irrigation to reduce this heat stress, and also evaporative demand, is commonly referred to as evaporative cooling (EC) irrigation. Evaporative cooling can reduce blossom drop in a number of crops. Most EC irrigation has been used for fruit, vegetable, and nursery crops, which have a value sufficient to justify the added expense of EC irrigation.

WTC System Management based on Daily Weather Forecasts

Water table management has a high potential for achieving maximum crop production and water use efficiency if properly controlled to compensate for changes in weather conditions. The timing of changes needed in the system operation to manage optimally the water table depth is a major problem for farmers, especially in coastal areas with fine textured soils. In the Mississippi Delta, for example, frequent occurrences of rainfall can cause large variations in water table depth because of the small, 2 to 6%, drainable soil porosity. A method and criteria was developed for using the rainfall probability data in the daily weather forecasts issued by the National Weather Service (NWS) to compute a Rainfall Probability Index (RPI), which in turn could aid the farmer in deciding when pumping of subirrigation water should be stopped in advance of predicted significant rainfall. Computer simulation results showed that this technique not only reduced the potential occurrences of excessive soil-water events, but significantly improved the efficiency of utilizing rainfall received by minimizing subirrigation pumping. Following other computer simulation studies to evaluate the use of the RPI concept to initiate drainage of the water table control system in advance of predicted rainfall it was concluded that the RPI concept was best utilized in managing subirrigation, that is, to stop irrigation pumping in advance of predicted rainfall. Advance drainage often caused a simulated over-drainage of the soil profile when predicted rainfall did not occur. Consequently, changes in the outlet water level to regulate or permit drainage from the subsurface conduit system should be implemented only when the groundwater level (water table) becomes closer than 200 to 300 mm below the soil surface (Fouss et al. 1990).

Summary

The water management system required for specific applications in the southeastern U. S. will depend upon many factors. If a water table exists in the soil profile much of the year, especially during the growing season, and the topography is relatively flat, a WTC system may be appropriate. Otherwise, a sprinkler or microirrigation system may be appropriate, depending upon the field size and shape, soil, crop, and water supply. In either case, good management of the system is extremely important, possibly more so in this area than in arid areas although the relative size of irrigated areas and volume of water required are much lower. Because irrigation is not required to produce most crops, the need for a share of available water supplies as perceived by the general public and government regulatory agencies may be extremely low or nonexistent. Consequently, as competition for water increases, agriculture may have a relatively more difficult task in obtaining or retaining a share of the water supply.

Water table control systems are capable of providing both subsurface drainage and subirrigation, depending upon the mode in which the system is operated. The system is designed to provide optimal control of water in the soil profile; however, the proper operating mode much be selected for the existing condition, either excess or deficit soil water content. The possibility of automating the mode selection process and incorporating rainfall probability and computer-based models were discussed.

Irrigation managers in Southeast must first select an objective based on expected yields, resource availability, and expected market prices. The irrigation management strategy to be used depends upon the type of irrigation system; management effort available; soil, crop, and climate factors; and water supply. Various water management methods (for either conventional irrigation and WTC) are available and applicable to this area, but utilization of these techniques is relatively low. Because of the need to include rainfall in the management scheme, computer-based models offer several advantages, including the opportunity to incorporate rainfall forecasts and schedule water management actions several days in advance. Utilization of rainfall improves profitability by reducing operating costs and can reduce the adverse effects of wet soils on crop yield. Available technology to assist in irrigation management currently exceeds its general application by growers and managers. In the final analysis, the adoption and effective utilization of any technology to improve water management in the Southeast will depend upon economic considerations; increased profitability through increased income or reduced cost.

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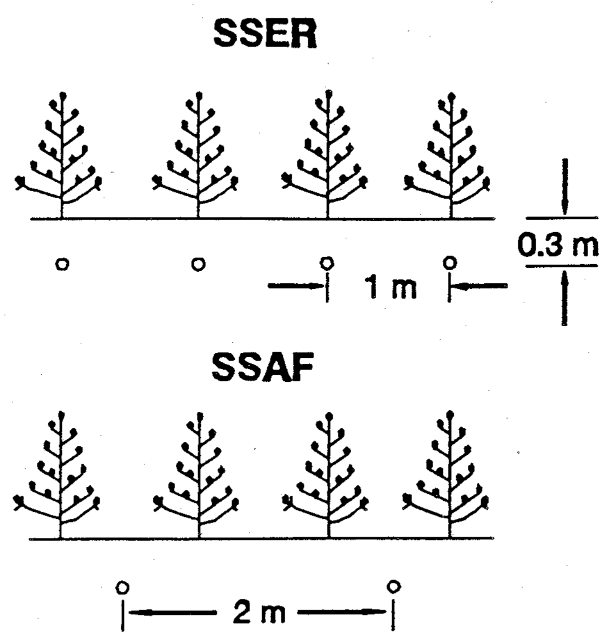

Fig. 1. -- Profile Schematic of Subsurface Microirrigation for Agronomic Crops Showing Two Lateral Spacings (1 or 2 m); SSER is for Subsurface Every Row and SSAF is for Subsurface Altenate Furrows.

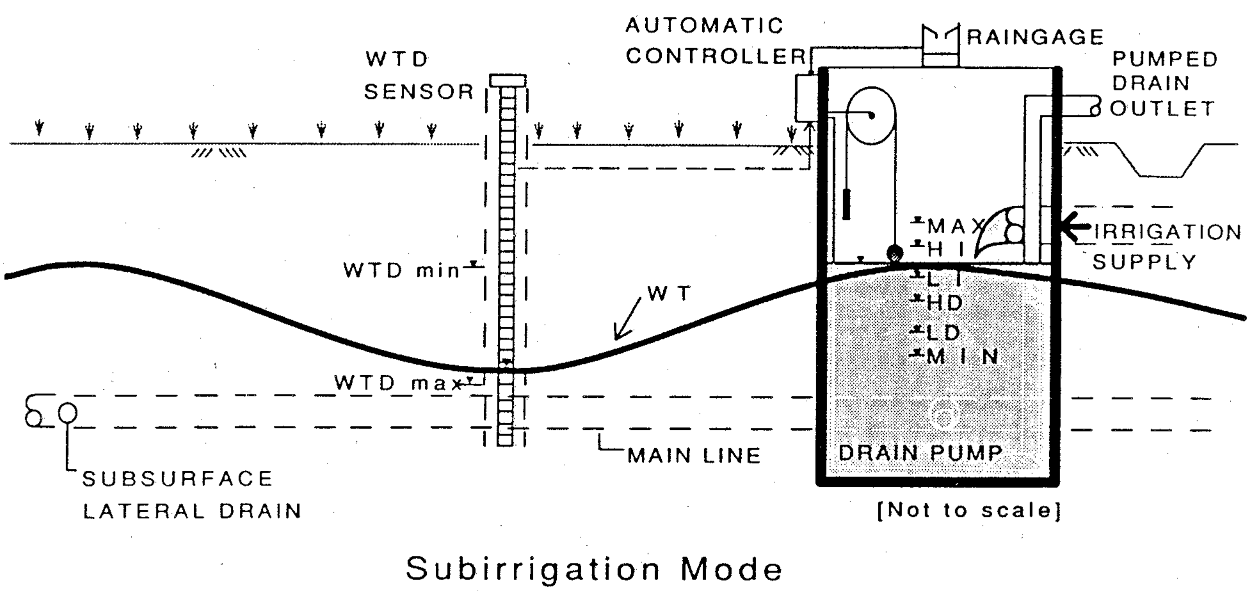

Fig. 2. -- Schematic cross-section profile of automated outlet water level control sump in subirrigation mode of operation; water table depth (WTD) at the midpoint between drains is continuously monitored with an electrical water level sensor.