Subirrigation System Control for Water use Efficiency

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ABSTRACT

A field experiment and a computer simulation analysis were conducted to evaluate the water requirements of subirrigation under three methods of system control. First year results from the field experiment indicate that irrigation water requirements can be reduced by controlling the system such that the midpoint water table depth is allowed to fluctuate within certain limits.

A simulation model based on numerical solutions to the Boussinesq equation was developed to allow comparison between the control methods using historical weather records. Several simulations were conducted for each control method to optimize the set points for starting and stopping subirrigation for the given method. Using the optimum set points, the simulations predicted a decreased irrigation requirement when the midpoint water table depth was allowed to fluctuate. The irrigation requirement was decreased by an average of 6.7% over constant water level control for five years of simulations. Much larger differences could have occurred had the set points not been optimized. That is, there is potentially more difference in irrigation water requirements for different set points within a given control method than between two different control methods.

The results indicate that there is a good potential for reducing irrigation requirements of subirrigation. A slight modification in the way in which subirrigation systems are currently controlled can result in decreased subirrigation water usage.

INTRODUCTION

Irrigation is the major user and consumer of water in the United States, accounting for 47% of the withdrawals and 81% of the consumptive use of fresh water supplies (USDA, 1980). The number of irrigated acres will likely continue to increase as will other demands for limited water supplies. Therefore, it will become increasingly important to maximize water use efficiency of irrigation systems.

Many soils require improved drainage to provide trafficable conditions for field operations and a suitable plant environment. In fields that possess certain physical characteristics, a combined drainage-subirrigation system can perform both drainage and irrigation functions (Fox et al. 1956). Doty and Parsons (1979) showed that subirrigation provided nearly all the water required by corn during two growing seasons. Skaggs et al. (1972) found that subirrigation provided more than enough water to the root zone of potato and corn for 7.5 m and 15 m drain spacings in a Lumbee sandy loam soil but was not able to supply enough water when the spacing was 30 m. This demonstrates that the operation of the system during both drainage and subirrigation must be considered in design (Skaggs, 1979).

With the effectiveness of subirrigation established, research has been directed toward evaluation of other important characteristics of subirrigation such as water and energy use efficiency. Strickland et al. (1981) compared the water and energy requirements of subirrigation and center pivot irrigation. The two systems studied were located on similar fields 8 km apart in South Carolina. They reported that the total water applied (rainfall plus irrigation) to the subirrigation site was approximately 7 cm greater than was applied to the center pivot site. It was also shown that subirrigation required only 25% of the energy used by the center pivot system.

Massey et al. (1981) simulated the water and energy requirements of subirrigation and sprinkler irrigation for three field sites in North Carolina. Twenty-seven years of continuous weather data from Wilson, N.C. were used for the simulations. Their results showed that subirrigation required an average of 4 to 8 cm more water than did sprinkler irrigation.

There are three principal reasons for the increased water required by subirrigation. First, if the water table is deep prior to initiating subirrigation, several centimeters of water may need to be pumped to bring the water table up to the desired operating height. Second, water is lost from the field by lateral seepage to adjacent nonirrigated areas and by deep seepage. Finally, the high water table present during subirrigation reduces the soil profile storage available for rainfall, thus increasing surface runoff.

The water required during the start of subirrigation can be minimized by blocking the drainage outlets to control drainage as soon as possible after planting. Seepage losses can be minimized by controlling the water level in adjacent ditches or canals and by installing the systems on sites that meet the requirements specified by Fox et al. (1956). Methods for reducing runoff and drainage from a subirrigated field have not been adequately determined.

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Most subirrigation systems are currently designed to hold the water level at a constant depth from the soil surface with only minor changes in its position occurring due to diurnal variations in evapotranspiration (ET). It is hypothesized that runoff and excess drainage could be minimized by controlling the system such that the water table is allowed to fluctuate within prescribed limits. In such a system, the water table would be allowed to fall due to ET until it reaches a depth that could no longer supply adequate water to the root zone. At this point the pump would be started and the water table raised to some maximum height that would not interfere with plant growth. The pump would then be turned off and the cycle repeated. It is likely that some rainfall events would occur when the water table is deep and therefore more of this rainfall could be stored in the increased unsaturated zone above the water table.

The purpose of this paper is to present the results of a study to test the hypothesis stated above. In a field experiment, four drainage-subirrigations systems were installed in one field to compare the water requirements under different methods of water table control. A second approach was to develop a computer simulation model to describe the operations of a controlled subirrigation-drainage system. The model was then used to predict and compare the subirrigation water use under different operating conditions using historical weather data.

FIELD STUDY

Four drainage-subirrigation systems were installed in a field on the A.R. Burnette farm in Edgecombe County, N.C. The multiple systems allow simultaneous testing of several cases of water table control during subirrigation. The drainage-subirrigation systems were installed in part of a 20 ha field which is bordered on one side by Ballahack Creek, a straight channelized drainage canal. The field is nearly flat with a slope of 0.2% towards Ballahack Creek. The soil is classified as a Portsmouth sandy loam (fine loamy, mixed, thermic, Typic Umbraqualt). The surface horizon is 0.25 to 0.5 m deep overlying a sandy clay loam subsoil that extends to a depth of 5 to 6 m (Massey, 1981). Two test holes revealed a restricting layer of tight clay, which may be considered impermeable for drainage purposes, at a depth of approximately 6 m.

Each subirrigation system covers an area of approximately 1.5 ha. Each system has eight lateral drains 122 m long spaced 15 m apart (Figure 1). The laterals are connected in groups of four to a solid header line which in turn is connected to one side of a head tank. The laterals are 10 cm diameter corrugated plastic drain tubing. The header lines are 10 cm diameter solid corrugated tubing. Lateral and header lines were plowed in to a depth of 1 m. The outlet drains from the head tanks to Ballahack Creek are 12.5 cm in diameter and are placed at a depth of 1.5 m. A sketch of the drainage-subirrigation systems is shown in Fig. 1.

The subirrigation systems installed for this study utilize a head tank for control of the water level above the drain outlets. The head tanks were designed to serve two purposes:

1. To provide a convenient location for independently measuring the drainage flowrates from two sets of four laterals.

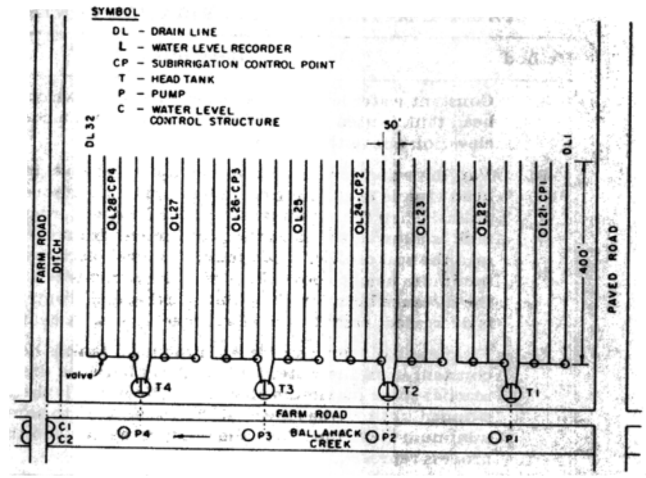

Fig. 1—Experimental system layout

2. To allow precise control of the water level above the drains during subirrigation and drainage of excess soil water after rainfall events.

Sheet metal tanks, 1.8 m in diameter and 2.4 m deep, were buried to a depth of approximately 2.1 m. The tanks were divided into three sections by two plywood boards as shown in Fig. 1. The boards are referred to as the divider board and the outlet board. The purpose of the divider board is to keep the drain flow from two sets of laterals separate. The drain flowrates are measured using calibrated weirs and stage recorders which are mounted on each side of the divider board. Weirs are mounted at two elevations in the outlet board on each side of the divider. During subirrigation the lower drainage weirs are covered and the water level in the tank is raised above the top of the divider board thus causing both sets of laterals to act as a single system. The upper (overflow) weirs allow drainage of excess rainfall occurring during subirrigation. After the growing season, covers are removed from the drainage weirs and the system is allowed to function as a conventional drainage system.

Irrigation water is supplied from Ballahack Creek. Four 1/3 hp submersible sump pumps were installed in slotted drums anchored to the creek bottom. Each pump can supply approximately 4.1 L/s of irrigation water to the corresponding head tank. The water is passed through a fabric filter to remove as much organic residue and silt as possible before entering the drain lines.

Each subirrigation system is controlled by two float switches. One switch is located in the head tank and the other is placed midway between two lateral drains. The pump starts and stops in response to either or both switches depending on the type of system control. A timer on the control panel measures the time each pump is on. The volume pumped is determined by the pump flowrate and the number of hours of operation.

The water table position in the field during subirigation is measured by eight Stevens Type F water level recorders located midway between drains as shown in Fig. 1. The water levels in the head tanks are also continuously recorded. The volume of drainage due to rainfall events during subirrigation is determined from the recorded elevation above the overflow weir which is st at a depth of approximately 50 cm below the soil surface.

A detailed description of the experimental subirrigation systems is presented by Smith (1983).

TABLE 1. METHOD OF SUBIRRIGATION CONTROL

Method	Description
A	Constant water level in the outlet: the float switch in the head tank is used to hold the tank water level a constant elevation above the drains.
B	Varying water level in the outlet: the water level in the head tank is raised to some maximum height above the drains. Then the pump is shut off and the water level in the tank is allowed to fall as the water moves from the drains into the soil profile. When the water level reaches some minimum height above the drains the pump is restarted. As the distance between the pump starting and stopping points is decreased, case B control approaches case A control.
C	Field control: the water level in the head tank is held constant until the water table midway between drains reaches some maximum elevation. The pump is then stopped until ET has lowered the water table to some minimum elevation. Then the pump is started and the process repeated.

EXPERIMENTAL RESULTS AND DISCUSSION

The experimental subirrigation systems were installed during the summer and fall of 1981. Corn was planted in the field on April 7th and subirrigation was initiated on May 10, 1982.

The systems were designed to allow three subirrigation control methods to be tested (Table 1). Control method A is representative of the way most existing subirrigation systems are operated, i.e. constant water level above the outlets. During dry periods, the position of the water table varies only slightly due to diurnal variations in ET. Method B would cause a somewhat greater variation in water table position than method A. Control method C would allow a much greater variation in water table position than the others. It was anticipated that this variation would allow for increased storage and utilization of rainfall thus decreasing irrigation water requirements.

The first few weeks of operation of the subirrigation systems yielded little reliable data. Those months were very wet and irrigation was not needed. The float switches in the tanks and field proved unreliable. The pumps therefore, would fail to start or would run continuously. As experience was gained in adjusting the switches, the system reliability as greatly increased.

Results from experimental systems 1 and 2 are plotted for the same 33-day period in Figs. 2 and 3. The figures show plots of water table depth and cumulative irrigation, rainfall, and drainage versus time.

Fig. 2 shows the results for a system operated under control method A. The water level in the tank was held approximately 50 cm ($\pm$ 3.5 cm) below the surface. The 7 cm variation in tank water level was as close to a constant head condition as practical with the pumps and switches used. The plot of the water table shows that during dry periods (days 200 to 205, 216 to 220) the subirrigation system was able to hold the water table at a relatively constant depth. Cumulative irrigation under this method of control is also plotted, along with rainfall and drainage, in Fig. 2. The relatively high water table maintained by this method of control caused drainage of excess water after some rainfall events.

Fig. 3 shows the results obtained under control method C. When the midpoint water table depth exceeded 85 cm, the pump was started and the water level in the tank was held 50 cm above the drains. The pump was stopped when the midpoint water table was

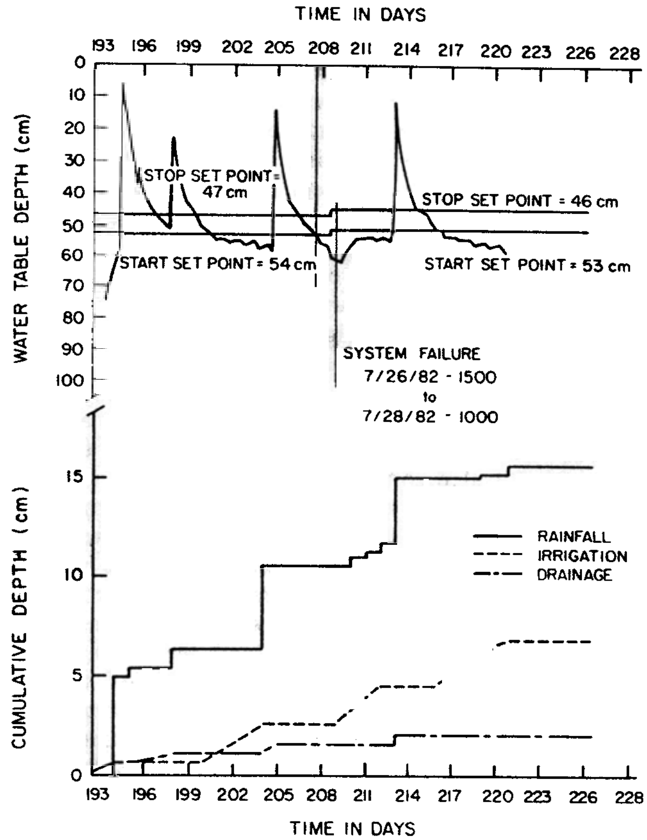

Fig. 2—Midpoint water table depth and cumulative depths of rainfall, irrigation, and drainage for Experimental System 1 operating under control method A.

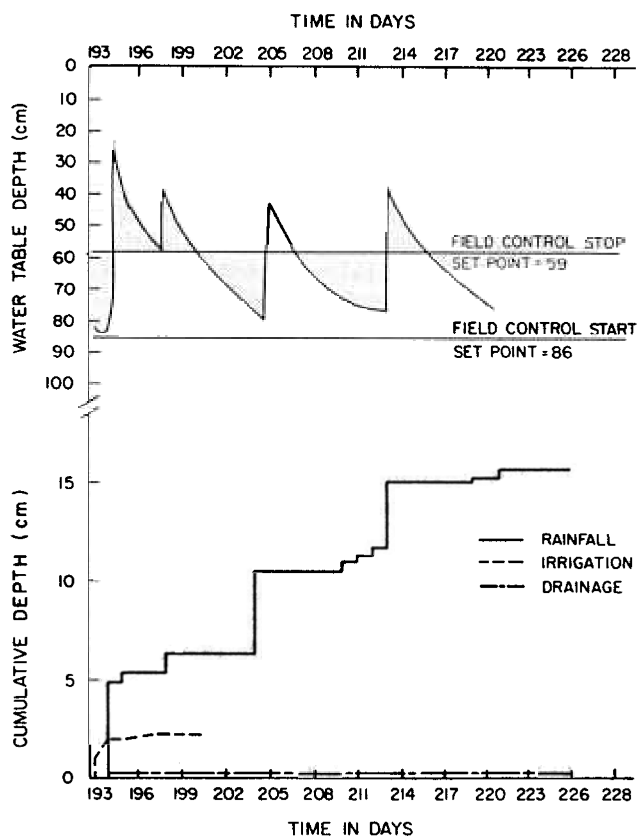

Fig. 3—Midpoint water table depth and cumulative depths of rainfall, irrigation, and drainage for Experimental System 2 operating under control method C.

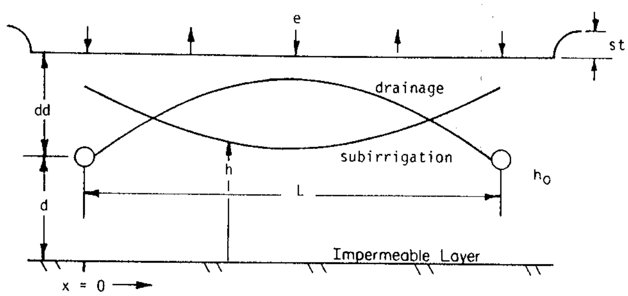

Fig. 4—Schematic of water table profile during subirrigation and drainage.

raised to within 60 cm of the soil surface. During the period shown, the water table fell low enough to start the pump only once (day 193). Rainfall was sufficient to keep the water table higher than the 85 cm depth for the rest of the period. During dry periods, the water table depth constantly increased. Fortuitously, rainfall events occurred just before the water table was deep enough to start the system. Since the water table was low when the rainfall events occurred, most of the rain was stored in the soil profile safely below the root zone and drainage from the system was negligible.

The data presented for the two systems shows that the method of control had a large influence on the amount of water applied. Control method A required 6.9 cm of irrigation during the 33 day period analyzed, while method C required only 2.1 cm of irrigation. A total of 1.9 cm of excess water was drained from method A while negligible drainage was obtained from control method C.

MODELING SUBIRRIGATION

Solutions to the Boussinesq equation for water movement under subirrigation and drainage conditions were used to model the system performance over several growing seasons. The model evaluates the water table position along with drainage, irrigation, and runoff volumes continuously during the growing season for corn. It was used to determine irrigation water requirements of subirrigation under different control methods.

MODEL DEVELOPMENT

A sketch of the water table profile during subirrigation and drainage is shown in Fig. 4. Definitions of symbols in Fig. 4 are as follows: L is the drain spacing, d is the elevation of the drains above the impermeable layer, h is the elevation of the water table above the impermeable layer, st is the depth to which water may pond on the soil surface, and e is the rate of infiltration or vertical losses due to ET or deep seepage (e is negative for losses).

If water movement in the unsaturated zone is neglected and the Dupuit-Forchheimer (D-F) assumptions are used, the governing equation for unsteady water movement during drainage or subirrigation may be described by the Boussinesq equation:

$$f(h)\frac{\partial h}{\partial t} = \frac{\partial}{\partial x}\left[Kh\frac{\partial h}{\partial x}\right] + e \quad \ldots\ldots\ldots\ldots\ldots\ldots [1]$$

Where K is the saturated lateral hydraulic conductivity, f is the drainable porosity, x is the distance from the drains, and t is time.

The D-F assumptions used in equation [1] do not account for convergence losses near the drains. An approximate method of correcting for these losses is to use the Hooghoudt equivalent depth concept as proposed by van Schilfgaarde (1963). The equivalent depth from the drain to the impermeable layer, d_e, can be calculated from equations presented by Moody (1966) and substituted for d in Fig. 4. The h values are then adjusted accordingly.

Boundary and initial conditions for subirrigation and drainage may be written as,

$$h = h_o \quad , x = 0 \quad , t > 0 \quad \ldots\ldots\ldots\ldots\ldots [2a]$$

$$\frac{\partial h}{\partial x} = 0 \quad , x = L/2 \quad , t \geq 0 \quad \ldots\ldots\ldots\ldots\ldots [2b]$$

$$h = h_i(x) \quad , 0 \leq x \leq L/2 \; , t = 0 \quad \ldots\ldots\ldots\ldots\ldots [2c]$$

where $h_i(x)$ is the water table elevation as a function of x at t = 0, when the simulation begins; h_o is dependent on the type of control being simulated, the flowrate into or out of the drains, and the pump flowrate (on or off). This boundary condition will be discussed in more detail in subsequent sections.

Solutions of equation [1] were obtained using finite difference techniques. Solutions for h are calculated for fifty nodes (x = 0.01 L) between x = 0 and x = L/2 every two minutes during the simulation. Solutions of the water table response during subirrigation and drainage were checked by comparing the model results with solutions presented by Skaggs (1973, 1975).

Solutions to the Boussinesq equation describe the water table elevation as a function of x and t; i.e. h = h(x,t). The flowrate to or from the drain can be determined by direct application of Darcy's law with the slope of the water table at the drain determining whether the profile is being irrigated or drained at a particular time.

Rainfall is assumed to infiltrate until the water table reaches the soil surface. The infiltration rate is then set equal to rate at which the infiltrating water is being removed from the profile by drainage. If the rainfall rate exceeds the reduced infiltration rate, water is ponded on the soil surface to the specified maximum depth of surface storage. If surface storage is filled, additional rainfall is considered to be runoff.

The daily ET is distributed sinusoidally during daylight hours. If rainfall occurs during an hour with ET, the ET rate is set equal to zero. For the cases considered in this study, the water table is held high so that soil water available to plants is assumed adequate to meet ET requirements.

The model inputs include dimensions of the subirrigation system (drain spacing, drain depth, etc.), soil properties, and climatic records of hourly rainfall and daily potential ET. A listing of the FORTRAN source code of the model and full documentation is presented by Smith (1983).

SIMULATIONS

The model was used to evaluate and compare the irrigation water requirements and water table response of subirrigation for three methods of control (Table 1).

TABLE 2. COMMON MODEL INPUT VARIABLES USED IN ALL SIMULATIONS

Variable	Value					
Drain spacing	152 cm					
Drain depth	99.6 cm					
Length of lateral	12200 cm					
Soil profile depth (to impermeable layer)	188 cm					
Allowable depth of surface storage	0.25 cm					
Depth to bottom of layer	50 cm		188			
Sat. Hyd. Conductivity of layer	13 cm/h		5			
Depth to bottom of layer	0 cm	10.0	20.0	30.0	40.0	188.3
Drainage porosity of layer	0.02	0.027	0.038	0.048	0.05	0.05

The first step of the evaluation was to determine the model inputs which would be common to all three cases. The second step was to simulate each case for a range of control settings. The results of step two were used to determine the optimum control settings for each case. The third step was to simulate each case for five years of historical weather data and compare the results.

The model inputs common to all control methods are those which represent the physical layout of the subirrigation system and soil properties. The switch settings in the head tank and field which control the pump are dependent upon the control method being simulated.

The system characteristics and dimensions used in the simulations were chosen to represent the experimental subirrigation system described previously (Table 2). The actual depth to the impermeable layer was replaced with an equivalent depth as described in the section on model development. The soil properties used in the simulations are based upon field measurements at the experimental site. These properties were presented by Massey et al. (1981) for their site 2 and are given in Table 2.

The settings of the switch located in the head tank are represented in the model by the variables tankh and tankl. The settings of the switch located midway between drains in the field are represented in the model by the variables fieldh and fieldl. If either control methods A or B is being simulated, water is pumped into the tank until the tank water level reaches tankh. The pump is then turned off until the tank water level falls to tankl. If method C is being simulated, the pump will come on only if the water table has fallen below fieldl. When this condition is present, the water level in the tank is held between tankh and tankl. Once the water table reaches fieldh, the pump is shut off and will not start again until the water table falls below fieldl. A schematic of a subirrigation system showing the relative positions of the switch settings is shown in Fig. 5.

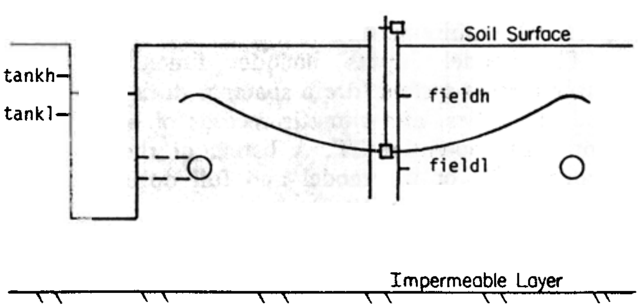

Fig. 5—Schematic of subirrigation system showing position of control settings used in model.

When control method A was being simulated, tankh was always 2.5 cm higher than tankl. This represents the maximum achievable degree of water level control in the experimental system. In all simulations of control method B, tankh was set at 50.5 cm below the soil surface. This is as high as the water level could be raised since the tank overflow weirs were set at 50 cm. During the initial simulations, tankl was varied. When control method C was bieng simulated, tankh and tankl were set at 50.5 and 53 cm, respectively. Fieldh was set at 60 cm which is the highest level to which the water table could be raised based on the settings of tankh and tankl as previously described. The value of fieldl was varied during the initial simulations.

RESULTS AND DISCUSSION

Simulations were run for the range of possible control settings for each control method. This was done to optimize control settings for each method prior to conducting simulations for comparison of the three control methods. These initial simulations were run using weather records from Wilson, N.C. for 1978. This year was assumed to be representative of average rainfall conditions during the growing season. All simulations were run for the period April 1 to August 15 which is the normal growing season for corn in eastern N.C. The optimum setting for each control method was the one that minimized irrigation water applied while satisfying plant needs.

Results of varying the "constant" height of water above the drains for control method A are shown in Fig. 6. As the tank water level is held at increasing depths from the soil surface (decreasing height above the drains), the irrigation volume decreases as does the volume of excess water drained from the top 50 cm of the

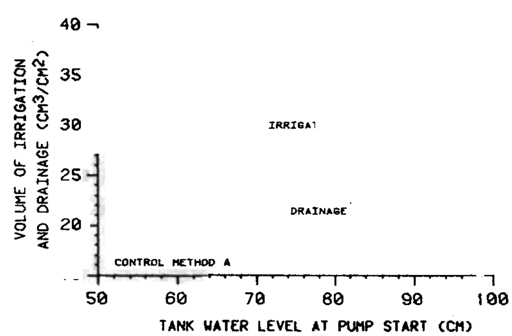

Fig. 6—Simulated irrigation and drainage volumes as affected by constant water level in tank for control method A. Tank water level is given in centimeters below soil surface.

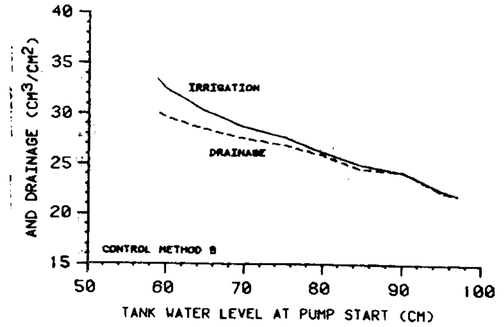

Fig. 7—Simulated irrigation and drainage volumes as affected by the tank water level at pump start (tankl) for control method B. Tank water level is given in centimeters below soil surface.

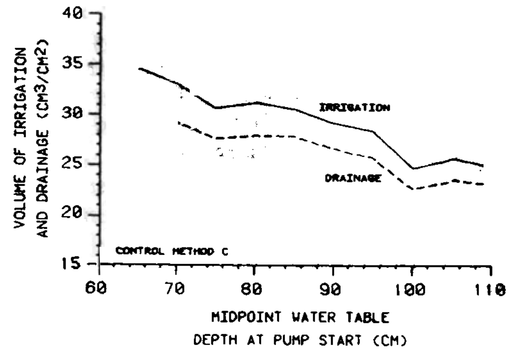

Fig. 8—Simulated and drainage volumes as affected by midpoint water table depth at pump start (fieldl) for control method C.

soil profile. This result was expected because lower controlled water levels in the drainage outlet (tank) decrease field water table elevations and drainage, and increase storage available in the unsaturated zone for infiltrating rainfall. As more rainfall is stored, the irrigation requirements are decreased. Similar results are obtained for control method B as shown in Fig. 7. For field control (control method C), the volumes of irrigation and drainage again decrease with increasing depth when the pump is started (Fig. 8).

The combined results of varying control levels for the three cases lead to the general conclusion that the water table during subirrigation should be held as deep as possible in order to maximize utilization of rainfall and minimize the amount of water pumped for irrigation. Note that, in the limit, the least amount of water would be used if there was no pumping and the water table was not raised at all. However, consideration must also be given to the ability of the water table control system to supply sufficient water to the crop root zone.

Subirrigation water is supplied to the root zone by upward water movement from the water table through the unsaturated zone. The rate of upward flux decreases rapidly as the distance between the water table and the evaporating surface increases. The relationship between upward flux and water table depth was calculated for the experimental site by Massey et al. (1981). This relationship is shown in Figure 9. The root zone for corn was assumed to be 30 cm deep. The maximum rate of ET for corn in eastern North Carolina is about 0.6 cm/day. If the bottom of the root zone is assumed to be the evaporating surface, then the maximum rate of ET could be supplied from a water table depth of 70 cm (30 cm plus 40 cm from Fig. 9) or less.

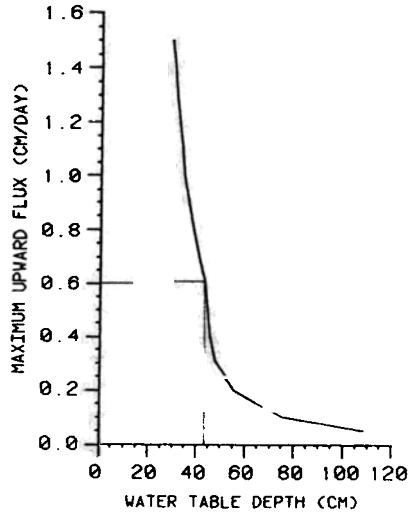

Fig. 9—Maximum steady rate of upward water movement as affected by water table depth.

When the water table falls below 70 cm the plants must remove water from the root zone to meet ET requirements. The length of time that ET can be met from water stored in the root zone depends on the volumetric water content of the soil when depletion starts, the water content at the wilting point, and the ET rate.

The number of days that crop ET requirements could be met by drying out the root zone was calculated as follows. The soil water content was assumed to be in hydrostatic equilibrium with the water table as long as the upward flux was sufficient to meet ET requirements. Thus the soil moisture tensions at the top of the root zone when removal of water from the root zone begins is 70 cm. The soil water contents at a tension of 70 cm and at the wilting point are 0.41 and 0.18 cm^3/cm^3, respectively (Massey et al., 1981). If the daily ET rate is assumed to be 0.6 cm/day and we allow 50% moisture depletion, then there would be sufficient water in the root zone to meet crop requirements for 6 days. Therefore, if the subirrigation is to adequately supply the crop water requirements, the controls must be set such that the water table depth will not exceed 70 cm for longer than 6 days at a time.

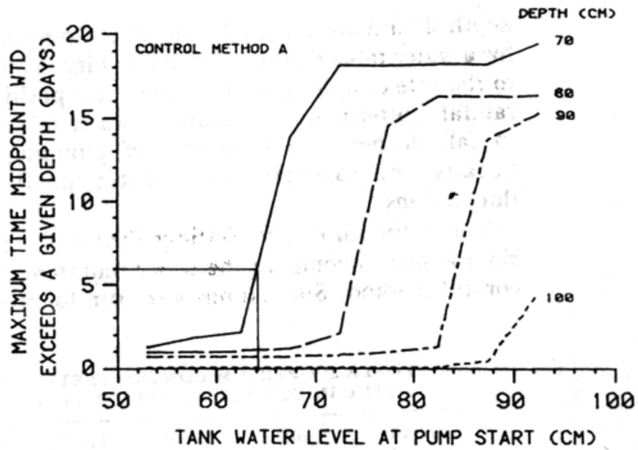

Fig. 10—Maximum time that midpoint water table depth exceeds a given depth as affected by the constant water level in the tank for method A.

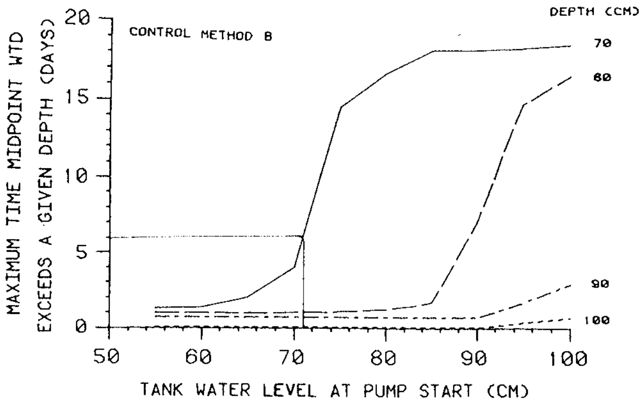

Fig. 11—Maximum time that the midpoint water table depth exceeds a given depth as affected by the tank water level at pump start for method B.

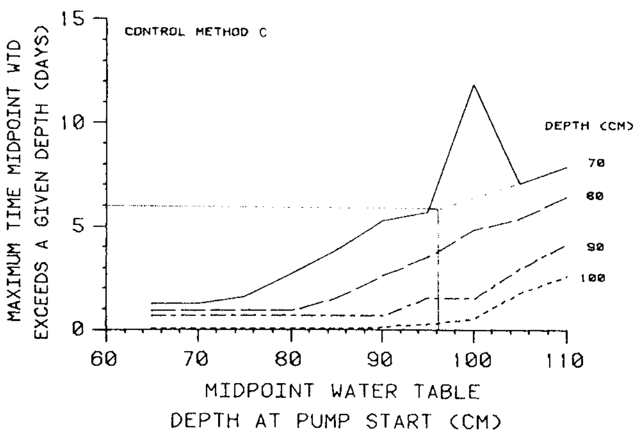

Fig. 12—Maximum time midpoint water table depth exceeds a given depth as affected by midpoint water table depth at pump start (fieldl) for control 1 method C.

The maximum length of time that the water table exceeds 70 cm with varying settings for control methods A, B, and C are presented in Figs. 10, 11, and 12, respectively. These figures are used to determine the optimum control settings for each case. Fig. 10 shows that for control method A, the water level in the tank should not exceed 64 cm from the soil surface. For control method B, the water level in the tank should not exceed 71 cm from the soil surface as shown in Fig. 11. Fig. 12 shows that the maximum midpoint water table depth should not exceed 95 cm. The odd response shown for a water table depth of 100 cm in Figs. 8 and 12 is due to the rate of cycling of the water table position and the rainfall pattern. As the midpoint water table is allowed to fall deeper, the frequency of pumping decreases because of rainfall and greater profile storage fluctuations.

The optimum control settings (Table 3) were used in simulations to compare the water requirements of each control method. Simulations were run for five years for each control method using weather records from Wilson, NC.

TABLE 3. OPTIMUM CONTROL SETTINGS USED IN COMPARISON SIMULATIONS

Control method	Tankh	Tankl	Fieldh	Fieldl
	(cm from soil surface)			
A	60.0	62.5	—	—
B	50.5	70.0	—	—
C	50.5	53.5	60.0	95.0

A summary of the total irrigation, drainage, and runoff for each simulation is presented in Table 4. Both control methods B and C resulted in decreased irrigation requirements when compared with method A. The average irrigation requirement for control method B was only 2.7% less than for method A. The maximum difference was 4.7%. Control method C resulted in a maximum decrease in irrigation of 12.1% compared with method A. The minimum decrease was 0.9% and the average decrease was 6.8%.

This indicates that control method C can reduce the irrigation water requirement of subirrigation. The differences shown here are not large, although a 12% decrease in pumping costs would be welcomed by most growers. It is apparent that the rainfall pattern has a large influence on the resulting water requirements. If the rainfall that occurs during the growing season is in the form of large events, the three control methods resulted in nearly identical subirrigation volumes. If the rainfall comes in frequent, light events, control method C will result in reduced water requirements. A comparison of the water table response to control methods A and C is presented in Fig. 13.

In interpreting the results given in Table 4, it is important to remember that the set points for each control method were optimized. Results plotted in Figs. 6 to 8 show that there is potentially more difference in subirrigation volumes between different set points within a given control method than between different control methods with optimized set points. Furthermore, the methods used for determining the set points were conservative in the direction of supplying an adequate supply of water for crop needs. For example, the

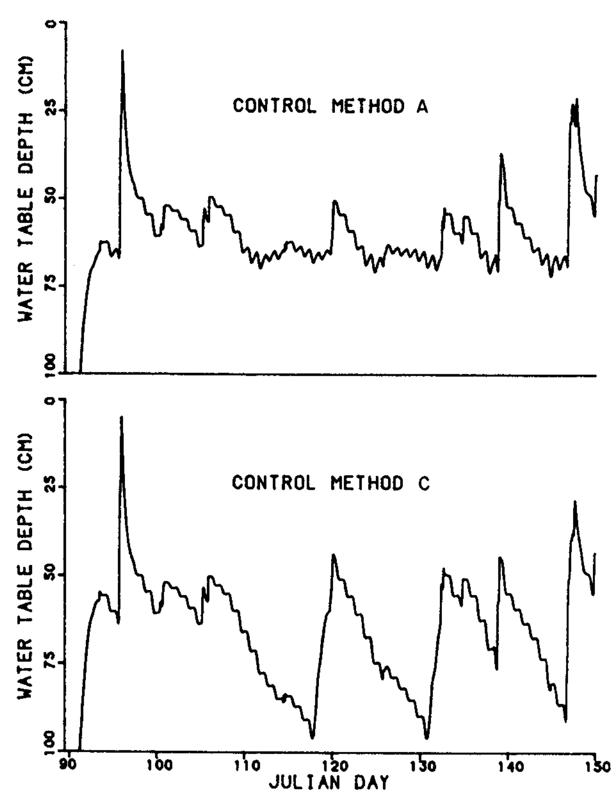

Fig. 13—Comparison of simulated midpoint water table response to two of the control methods.

TABLE 4. SIMULATED SUBIRRIGATION, DRAINAGE AND SURFACE RUNOFF VOLUMES FOR THREE CONTROL METHODS FOR FIVE YEARS OF WEATHER RECORDS

Control method	Parameter, cm	Simulation year 1963	1968	1975	1977	1978	Total	Average
ALL	Rainfall	53.29	62.32	56.88	35.04	54.33		52.37
	ET	48.46	49.64	51.52	56.09	51.48		51.44
	Subirrigation	28.95	29.79	31.77	42.83	30.25		32.72
	Drainage	24.92	31.62	25.79	12.57	28.05		24.59
	Runoff	6.59	8.32	9.78	5.86	3.43		6.80
B	Subirrigation	27.59	28.91	30.77	42.43	29.52		31.84
	Drainage	23.86	31.00	25.10	12.21	27.57		23.95
	Runoff	6.29	8.06	9.63	5.82	3.32		6.62
C	Subirrigation	25.61	26.19	31.49	40.72	28.53		30.51
	Drainage	22.39	29.04	25.09	10.80	25.86		22.82
	Runoff	5.78	7.30	8.87	5.73	3.47		6.23

maximum length of time that the water table was allowed to fall below the desired depth was determined by assuming that only 50% of the available water in the root zone would be used up. A more liberal assumption would have allowed a deeper set point and a reduction in the amount of subirrigation and drainage. The purpose here was to compare results for different control methods. While the procedures used to select the set points were somewhat conservative, they were the same for all control methods. The results emphasize the importance of optimizing the set points regardless of the control method used.

SUMMARY AND CONCLUSIONS

A field experiment and a computer simulation analysis were conducted to evaluate the water requirements of subirrigation under three methods of system control. First year results from the field experiments indicate that irrigation water requirements can be reduced by controlling the system such that the midpoint water table depth is allowed to fluctuate within certain limits.

A simulation model based on numerical solutions to the Boussinesq equation was developed to allow comparison between the control methods using historical weather records. Several simulations were conducted for each control method to optimize the set points for starting and stopping subirrigation for the given method. Using the optimum set points, the simulations predicted a decreased irrigation requirement when the midpoint water table depth was allowed to fluctuate. The irrigation requirement was decreased by an average of 6.7% over constant water level control for five years of simulations. Much larger differences could have occurred had the set points not been optimized. That is, there is potentially more difference in irrigation water requirements for different set points within a given control method than between two different control methods.

The results presented in this paper indicate that there is a good potential for reducing irrigation requirements of subirrigation by using a simple control system employing a float switch triggered by the field water level. A slight modification in the way in which subirrigation systems are currently controlled can result in decreased water usage.

References

1. Doty, C. W. and J. E. Parsons. 1979. Water requirements and water table variations for a controlled and reversible drainage system. TRANSACTIONS OF THE ASAE 22(3):532-536, 539.
2. Fox, R. L., J. T. Phelan and W. D. Criddle. 1956. Design of subirrigation systems. AGRICULTURAL ENGINEERING 37:103-108.
3. Massey, F. C., R. W. Skaggs and R. E. Sneed. 1981. Energy requirements of irrigation systems-subirrigation versus sprinkler irrigation. ASAE Paper No. 79-2543. ASAE, St. Joseph, MI 49085.
4. Moody, W. T. 1966. Nonlinear differential equation of drain spacing. Journal of the Irrigation and Drainage Division, ASCE, 92(IR2):1-9.
5. Skaggs, R. W., G. J. Kriz and R. Bernal. 1972. Irrigation through subsurface drains. Journal of the Irrigation and Drainage Division, ASCE, 90:363-373.
6. Skaggs, R. W. 1979. Water movement factors important to design and operation of subirrigation systems. ASAE Paper No. 79-2543. ASAE, St. Joseph, MI 49085.
7. Skaggs, R. W. 1973. Water table movement during subirrigation. TRANSACTIONS OF THE ASEA 16(5):988-993.
8. Skaggs, R. W. 1975. Drawdown solutions for simultaneous drainage and ET. Journal of the Irrigation and Drainage Division, ASCE, 101:279-291.
9. Smith, M. C. 1983. Subirrigation system control for water-use efficiency. Masters thesis. Department of Biological and Agricultural Engineering, N.C. State University, Raleigh.
10. Strickland, E. E., J. T. Ligon, C. W. Doty and T. V. Wilson. 1981. Water and energy requirements for subsurface and center-pivot irrigation. ASAE Paper No. 81-1069. ASAE, St. Joseph, MI 49085.
11. United States Department of Agriculture. 1980. Soil and Water Resources Conservation Act. 1980. Appraisal Review Draft, Part 1.
12. van Schilfgaarde, J. 1963. Design of tile drainage for falling water tables. Journal of the Irrigation and Drainage Division, ASCE, 89:1-13.