OPERATION OF WATER TABLE CONTROL SYSTEM FOR WATER QUALITY IMPROVEMENT

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INTRODUCTION

About 25% (i.e., 40 million hectares) of the total U.S. cropland needs drainage (U.S. Dept. Agric. 1987). Much of this land is usually flat, highly fertile, and has no serious erosion problems. These potentially productive wet soils are primarily located in the prairie and level uplands of the Midwest, the bottom lands of the Mississippi Valley, the bottom lands in the Piedmont areas of the South, the coastal plains of the East and South, and irrigated areas of the West (Schwab et al. 1993). During most or part of the year, these soils have shallow water tables that are potential sinks for agrochemicals that leach below the root zone. The frequently occurring shallow water table conditions in humid regions increase surface runoff with the potential of carrying residuals of applied agrochemicals (e.g., fertilizers and pesticides) to streams and lakes. In areas where water management facilities include subsurface drainage, agrochemicals that leach below the root zone may be carried off-site in subsurface drainage discharge.

The lower Mississippi River Valley (LMRV) contains about 2.5 million hectares that have been assessed as highly vulnerable to groundwater pollution by leachable chemicals and a slightly smaller amount of land evaluated as moderately vulnerable. The widespread use of agricultural chemicals, including fertilizers and pesticides, has been brought about by economic factors and farmers' efforts to obtain a fair return on their investment in crop production systems. In the Lower Mississippi Valley (LMV), several conditions exist and practices are followed that may contribute to groundwater contamination potential via transport of nutrients and pesticides through the root and vadose zones of the soil profile: (1) A relatively shallow depth in the soil profile to the alluvial aquifer; (2) the current use of many water soluble chemicals; (3) permeable soils, such as silt and sandy loams; (4) cracks that develop in the soil upon drying, creating preferential flow paths deep into the soil profile; (5) large annual rainfall amounts; and (6) tillage, drainage, and irrigation practices. There are major economic reasons for the continued use of pesticides for the foreseeable future in U.S. agriculture, especially in the LMV where hot and humid climate conditions enhance weed growth and insect infestation. Thus, there is the potential for extensive contamination of surface and groundwater resources in the LMV resulting from continued high fertilizer and pesticide use if current agrochemical application, soil and water management, and crop production practices are followed.

Integrated management of soil and water resources and agronomic cultural practices is necessary to insure environmentally sound crop production on shallow water table soils in humid areas (such as the LMV), and to reduce or eliminate potential pollution of water resources, including adjacent wetland areas. Integrated methodology is urgently needed to manage soil, water, ground cover, fertilizer and pesticide applications in such a way that fertilizers and pesticides are contained in their functional "action zones" of the soil profile. It should be possible to manage water table depth to control root-zone soil-water content such that plant fertilizer use efficiency is enhanced, thereby decreasing fertilizer needs and reducing nutrient pollution potential. Furthermore, recent research has shown that improved soil-water management increased early-season crop growth and provided canopy cover that decreased weed populations (Carter 1990). This decrease could reduce herbicide needs and thereby lower pollution potential. There is also an opportunity to reduce pollution by overall pesticide management practices, particularly for those pesticides that degrade as a function of soil moisture and aeration conditions. The reduced need for fertilizers and pesticides would thus increase profits to farmers.

Variable rainfall amounts and uncertain times of occurrence in most humid regions, and especially in the LMV, create a need for water management systems which will compensate for both excess and deficit soil-water conditions. A dual purpose subsurface conduit system for subdrainage and subirrigation is becoming popular in many humid areas of the U.S. and eastern Canada (Skaggs 1980; Fouss et al. 1990). New technology is needed to properly design and operate these water table management systems; for example, when to subirrigate and when to control subdrainage effluent or permit "free" drainage of the soil profile to provide the best possible root-zone moisture conditions for crop production, while reducing runoff, erosion, and pollution. In many cases, automatic control of the water table management system may be merited (Fouss et al. 1990). In some humid regions, the probability of predicted rainfall in National Weather Service forecasts, particularly the new 7-day Forecast (SRCC 1994), may soon become accurate enough to permit adjustment of day-to-day operation of water management systems (Fouss and Cooper 1988) and/or timing of fertilizer and pesticide applications. Principal management objectives may be to: (a) increase the effectiveness of fertilizers and pesticides applied and reduce the potential of losses; (b) reduce the occurrences of severe excess soil-water events and the duration of deficit soil-water conditions; and (c) improve the efficiency of utilizing rainfall received, thus minimizing the need for pumping irrigation water.

PROJECT DESCRIPTION

A comprehensive research program has been initiated in the lower Mississippi Valley to develop the technology to design and operate an integrated system for water-fertilizer-pesticide management. The overall objective is to evaluate various soil and water management strategies in terms of reduction in agrochemical (fertilizer and pesticide) losses in surface runoff, subsurface drainage effluent, or deep seepage, and improvements in agrochemical use efficiency and crop yield potential. The research involves both modeling and field plot experimentation, plus laboratory investigations. Too many variables are involved to optimize system design and operational performance based on field tests alone. Model development phases were begun early, permitting preliminary simulation results of proposed water management systems operation to help in the design of the field experiment and identify treatments and required measurements. The discussion in this paper covers the field research phases only.

The field project is located on the LSU Ben Hur Research Farm near Baton Rouge, Louisiana, on a Commerce silt loam soil which consists of layers of silt and clay mingled with sand lenses that were deposited by past Mississippi River overflows. Four water management treatments with four replications were installed in a randomized complete block design on 16 bordered 0.21-ha plots; the treatments include:

(I) SUR Only; surface drainage only [the subsurface drainlines are plugged]

(II) DRN-100; conventional subsurface drainage water table at 100 cm depth

(III) WTC-45; controlled shallow water table at 45 ± 5 cm depth

(IV) WTC-75; controlled deeper water table at 75 ± 5 cm depth.

Each plot, 35 m x 61 m, has a 0.15-m high earthen dike at the outer edge of each border, a 0.15 mm polyethylene subsurface barrier installed 0.3 m below the soil surface and extending down 2.0 m, three subsurface drainlines (102-mm diameter corrugated plastic tubing) installed at 15 m spacings and 1.25 m depth, a 300 mm diameter plastic pipe riser on the outlet of each drainline to control the outlet water level (these risers are housed in a 1.2-m square by 3.0-m deep steel sump), and an H-flume at the surface runoff outlet. Each plot is precision-graded to a 0.2% slope with about a 0.2% cross-slope. The drainlines next to the longitudinal borders control border or water table transition effects between adjacent plots. The area centered over the middle drainline (15 x 61 m) is assumed to be representative of an area in a larger field with the same drain spacing.

The project area is equipped and instrumented for automatic measurement and control of water table depth and microprocessor-controlled measurement and automatic sampling of surface runoff and subsurface drain outflow. Four electronic, microprocessor-based, data-logger /controller systems (one per replication) are used on the project to continuously measure/record experimental variables and parameters with various sensors (e.g., water table depth, soil temperature, rainfall, etc.) and to automatically operate all drainage pumps and irrigation valves to control the water table depth (for details see Willis et al. 1991, 1992).

Runoff from each plot is routed through an H-flume where it is automatically measured and sampled by a microproccess-controlled, refrigerated system. The runoff samples collected are proportional to runoff rate/volume and are analyzed for nutrient, pesticide, and sediment content. Subsurface drain effluent samples for the similar analyses are collected by an orifice-type device as water is pumped from the outlet water level control riser pipes for each center drainline; the sample volume is approximately 0.2 % of the total effluent. A composite effluent sample is collected for each storm event; a minimum 6-hour period with no more than 2.5 mm of rainfall defines the start of a new storm event.

Complete details of the experimental design, materials and equipment, operational procedures, instrumentation, and data acquisition for the project are presented by Willis et al. (1991, 1992).

Automated Water Table Control. For Treatments III and IV, the water table depths in the experimental plots are automatically maintained within the depth ranges specified by automated or feedback control of the water level at the subsurface drain outlet (i.e., the outlet riser pipe) to regulate subsurface-drainage and subirrigation flows (commonly referred to as controlled-drainage and subirrigation). For the controlled-drained mode of operation (during periods of potential excess soil-water), drainage water is pumped from the outlet riser pipe to a gravity flow channel to maintain the outlet water level within the desired range. Conversely, for the subirrigation mode (during periods of potential deficit soil-water conditions) water is supplied from an external source (e.g., a well) into the riser pipe to maintain the desired outlet water level. In the project, all on-and-off cycles of drainage pumps and irrigation pumps (or valves) are activated, as needed, by a microprocessor data-logger/controller system which monitors outlet water levels via electronic water pressure sensors in each riser pipe. The data-logger/controller system also continuously monitors the water table depth in all plots (midway between drainlines) via electrical water level sensors installed in 50 mm diameter plastic pipes (water table "wells"). If a plot water table depth becomes too shallow or deep, the outlet water level control thresholds (i.e., on-and-off limits for drainage/irrigation pump operation) are automatically adjusted upward or downward (called feedback adjustment) as needed to compensate and thus also control the plot water table depth within the desired range. A through discussion of feedback water table control is presented by Fouss et al. (1990).

Corn was planted May 25, 1994, and chemicals for weed and insect control were surface-applied. Planting was delayed approximately 30 days because of excessive wet weather in early May. Water table treatments were imposed and all subsequent runoff and subsurface drainage effluent was sampled. Corn yields are not reported for the 1994 season because of the late planting date.

RESULTS

Control of water table depth (WTD) in the 0.21 ha field plots was successfully accomplished by the automated adjustment of the water level at the outlet of the subsurface drainage system to regulate controlled-drainage (CD) and subirrigation (SI) flows. The electronic data-logger/controller system and microprocessor software developed to automatically monitor WTD and operate the water quality experiment, and to acquire all experimental data, worked very well during the 1994 startup season. The acquired data for the 1994 growing season are summarized in Table 1. For the controlled water table Treatment III (CD/SI at 45 $\pm$ 5 cm WTD) and Treatment IV (CD/SI at 75 $\pm$ 5 cm WTD), the water tables in the experimental area of these plots was maintained within 10 - 15 cm of the specified range, except during rainfall events when the outlet water level was automatically lowered. The growing season average WTDs are given in Table 1; the average WTD in Treatment III was about 30 cm deeper than the desired depth, but in Treatment IV was essentially maintained at the desired depth. The differences in water table control and fluctuation for the four treatments are shown in Figure 1 for the 1994 season (only replication 4 results are shown). Subdrainage was the greatest for Treatment II and the least for Treatment III. Treatment III required significantly more subirrigation than Treatment IV. A presentation of the results of the laboratory analyses to determine the agrochemical content in the surface runoff and subsurface drainage flow is given by Willis et al. (this Proceedings). Some lateral seepage between a few plots was detected during the season, but the plot border drainlines compensated for the differences in water table depths between adjacent plots, and the water tables in the experimental areas were maintained within an acceptable range.

The automated operation for the CD/SI treatments, which also implemented operational changes from SI to CD, or from CD to deep-drainage (DD), as needed to maintain the desired WTD, performed well for several storm events during 1994. For the CD/SI treatments, the automated system changes the mode of operation to CD if measured rainfall exceeds 25.4 mm within any 2-hr period and to the DD mode if the WTD is shallower than 20 cm for more than 2 hrs. After a change to the DD mode of operation, the automated system will change operation back to CD when the WTD recedes to the desired range. During the 1994 season, the shallow WTC system (Treatment III) was changed to the CD mode significantly more times than the deeper WTC system (Treatment IV). The water table in the surface drained only plots (Treatment I) was near or at the soil surface most often during the season, followed by the water table in the shallow WTC plots (Treatment III). The water table in the conventional drainage plots (Treatment II) was near or at the soil surface for the fewest number of rainfall events. A manual input to the data-logger/controller units is required to start or change to the SI mode of operation; this method permits consideration of the probability of rainfall in the weather forecast when deciding when to restart the SI mode. The 36-hr and 7-day forecasts from the U.S. National Weather Service were used in 1994 to schedule agrochemical applications and to initiate the SI mode of operation. The 7-day forecast shows much promise for future use in the lower Mississippi Valley.

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Table 1. Summary of 1994 Growing Season Monthly Average Water Table Depths, and Drainage Flows for Water Table Management Treatments in Water Quality Project.

Month	Rain	WTD, RO DRN/IRR	Treat. I (SUR-only)	Treat. II (DRN-100)	Treat. III (WTC-45)	Treat. IV (WTC-75)
	(mm)	(cm) *				
Jun	152.4	WTD	69 ± 15	112 ± 5	84 ± 20	81 ± 13
		RO	10.9	8.9	9.7	8.6
		DRN	---	3.3	0.8	1.5
		IRR	---	---	0.3	0.0
Jul	127.0	WTD	56 ± 18	104 ± 10	61 ± 15	76 ± 15
		RO	4.3	6.1	5.6	5.1
		DRN	---	4.1	1.0	1.0
		IRR	---	---	0.8	<0.3
Aug	83.8	WTD	69 ± 10	107 ± 3	61 ± 5	76 ± 5
		RO	<0.3	<0.3	<0.3	<0.3
		DRN	---	1.8	0.5	0.5
		IRR	---	---	1.0	0.0
Sep	53.3	WTD	84 ± 13	112 ± 5	74 ± 18	84 ± 10
		RO	0.0	0.0	0.0	0.0
		DRN	---	0.8	0.8	0.3
		IRR	---	---	1.0	0.5
G.S. Av.		WTD	69 ± 15	109 ± 5	71 ± 15	79 ± 10
& Tot.	416.6	RO	15.5	15.2	15.5	14.0
		DRN	---	9.9	3.0	3.3
		IRR	---	---	3.0	0.8

* WTD = Avg. & Std. Dev. of daily water table depth at the midpoint between drains in experimental plots (cm); RO = surface runoff from plots (cm); DRN = subsurface drainage flow (pumped) from outlet risers (cm); IRR = subirrigation water input to outlet risers (cm).

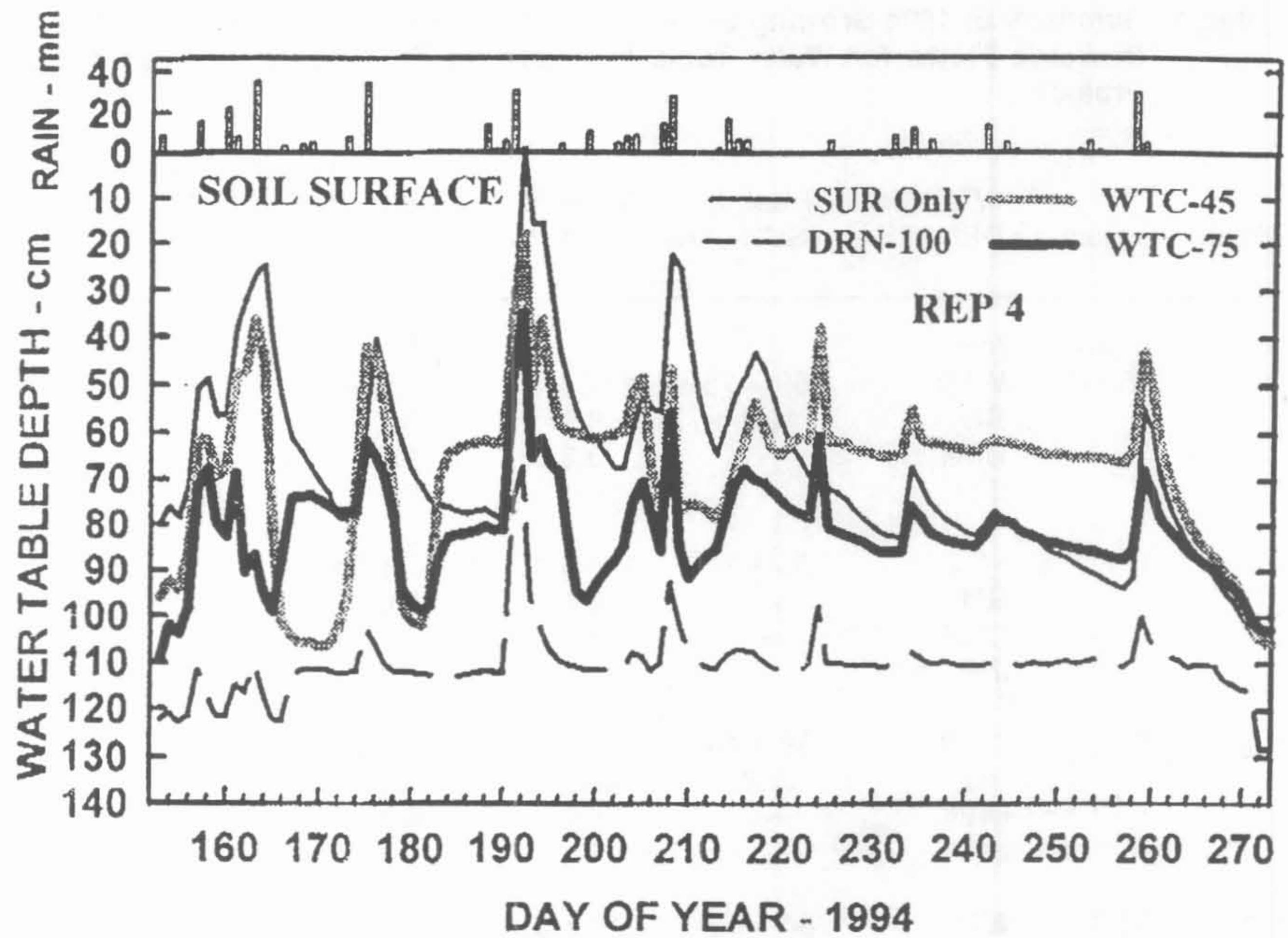

Figure 1 -- Comparison of four methods of water table control in water quality research project (Rep 4 only)