Journal of the Korean Society of Agricultural Engineers
Vol. 36, Dec. 1994

Effect of Drainage System on ET and Drainage Flows

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Abstract□The effects of drainage system on evapotranspiration and drainage flows are studied. Data from drainage field experiment at Castalia in North Central Branch, Ohio Agricultural Research and Development Center were used in this study. A water table management model, ADATP (Agricultural Drainage and Pesticide Transport), which was developed by combining the GLEAMS and the subsurface drainage part of the DRAINMOD model with several modifications, was evaluated and used to predict hydrologic components.

The ET is very much affected by the presence of tile drainage system but not significantly affected by the surface drainage system. The combined surface and subsurface drainage system gives the largest total outflow values while the surface drainage only system gives the smallest.

Comparisons of model predicted and measured values of surface runoff only, subsurface drainage only, and combined surface runoff and subsurface drainage system are in satisfactory agreement. The model predicted values are within the range of the variations of the observed replications in general. Based on the results of the model evaluation study, it is concluded that ADAPT model can be used to design water table management systems.

Keywords□Drainage, ET, ADAPT, water table management

I. Introduction

Agricultural drainage could be defined as the removal and disposal of excess water from agricultural lands(Soil Conservation Service, 1973). The purpose of the agricultural drainage is improvement of soil water condition to enhance agricultural use of land (Van Schilfgaarde, 1974). In the USA, 52.7 million hectares or one third of all cropland is drained artificially (Soil Conservation Service, 1973). Agricultural drainage can be made by either surface or subsurface drainage. In north cenral America, many poorly drained agricultural lands are drained by subsurface tile system.

The ADAPT(Agricultural Drainage and Pesticide Transport) model was developed by Alexander (1988) to provide a more complete model to simulate the quantity and quality of flows associated with water table management systems. It is developed by combining parts of the GLEAMS and DRAINMOD models. The GLEAMS model developed by Leonard et al.(1987) is a water quality model without subsurface drainage, while the DRAINMOD developed by Skaggs(1987) is a water table management model with subsurface drainage and subirrigation but without water quality component.

It is worth noting that the limitations of the two models with general acceptance seem to be complemented by each other. Therefore, intergrating the GLEAMS and DRAINMOD models into one model, ADAPT forms the basis of a comprehensive simulation model able to handle variety of water table management systems.

The ADAPT model has been improved by Ward et al.(1988), Schalk(1990) and Chung et al.(1992) by adding new algorithms to account for snow melt, deep seepage, and preferential flow and many other modifications.

The hydrologic component of the model is evaluated using data from long term field experiments in North Central Ohio. Ten years (1962~1971) surface and subsurface drainage field data from Castalia, Ohio are used to evaluate the hydrologic component of the ADAPT model.

The objectives of this study are : ① to evaluate the effects of the surface and subsurface drainage system on evapotranspiration and total drainage outflow, and ② to evaluate the ADAPT water table management model to predict the hydrologic components in the agricultural land.

Ⅱ. Field Experiment

Field experiment was conducted for a 10-year period(1962 to 1971) by Schwab et al.(1975) to study hydrologic performance with field crops and crop yields with respect to the tile and surface drainage systems. Experimental site was located at Castalia near Sandusky, the North Central Branch, Ohio Agricultural Research and Development Center. The experimental site was nearly flat(0.2 % slope) and the predominant soil type is Toledo silty clay. Each plot was 37m by 61m(0.55 acres).

Field plots were planted mostly in corn. Exceptions were 1965 and 1966 when soybeans and oats were planted. respectively.

Field installation consisted of three treatments : plots with surface drainage only, subsurface tile drainage only, and a combination of surface and subsurface drainage. 100mm diameter concrete pipe was used for tile drainage. Four replications were made. All of the plots were under the conventional tillage(fall plowing and spring disking), except replications 3 and 4 during the years 1968 through 1971 which were no till. Surface runoff and tile drainage flow data were recorded for the period March 1 to September 30 each year. In this study, all of the three treatments are used for comparison.

There were two major storms during the 10 year period : 19.1cm on July 13, 1966 and 29.7cm on July 5, 1969. Both storms exceeded 100 year return period rainfall and field site was inundated.

Surface and subsurface drainage are from rainfall and irrigation. Two sprinkler irrigations of 7.6 cm each were made except in years 1965 and 1969, when three and one applications of 7.6cm each were made respectively. Most applications were in June.

Ⅲ. Model Description

The ADAPT(Agricultural Drainage and Pesticide Transport) model is used to predict hydrologic component in the agricultural lands. The model was developed by Alexander(1988) to provide a more complete model to simulate the quantity and quality of flows associated with water table management system. The model is an extension of GLEAMS(Leonard et al., 1987) incorporated with subsurface drainage and subirrigation algorithm from DRAINMOD(Skaggs, 1978). The ADAPT model has been improved singnificantly by Ward et al.(1988). Schalk(1990), and Chung et al.(1992). The ADAPT model has three components, namely hydrology, erosion, and pesticide elements. It is written in FORTRAN language with the modular programming technique. Table 1 shows a comparison of modeling techniques for several items in GLEAMS, DRAINMOD, and ADAPT.

The flowchart of daily simulation of ADAPT is shown is Fig. 1. The first step in daily simulation is snowmelt. Then the model computes surface runoff in case of sufficient effective rainfall. The model includes macroflow, evapotranspiration, infiltration, subsurface drainage or subirrigation, and deep seepage.

Potential evapotranspiration(PET) can be calculated by either Ritchie's method or Dorenbos-Pruitt method. The latter is an added option in ADAPT. After determining the PET, evaporation and transpiration are computed separately as a function of leaf area index(LAI). A preliminary study showed that the PET predicted by the Ritchie's method was 10% larger than PET predicted

Table 1. A comparison of DRAINMOD, GLEAMS, and ADAPT modeling techniques.

ITEM	DRAINMOD	GLEAMS	ADAPT
LAYERS	5 Layers extending to impermeable layer	3~12 Layers extensing bottom of root zone	9 Layers extending to impermeable layer
WEATHER DATA	Hourly rain, daily radiation and temperature	Daily rain, monthyl radiation and temperature	Daily rain, radiation, windspeed, and temperature
SNOWMELT	NA*	Degree-day formula for snow accumulation and melt	Snowmelt by radiation, rainfall, conduction, convection, and condensation
RUNOFF	Computed from balance at soil surface	SCS curve number	SCS curve number. Antecedent soil moisture(two options)
MACROPORE FLOW	NA	NA	Soil surface crack due to drying
INFILTRATION	Green-Ampt Equation	Difference of rain and runoff	Green-Ampt Equation
ET	Thornthwaite's Method or any external method	Ritchie's Method	Ritchie's or Dorenbos-Pruitt Method
DRAINAGE/ SUBIRRIGATION	Kirkham's or Hooghoudt's Equation. Water table depth related to drainage volume.	NA	Kirkham's or Hooghoudt's Equation. Water table change defined by drainable porosity filling or emptying.
DEEP SEEPAGE	Darcy's Law	NA	Darcy's Law with unit hydraulic gradient

*NA means not applicable, model does not consider that process.

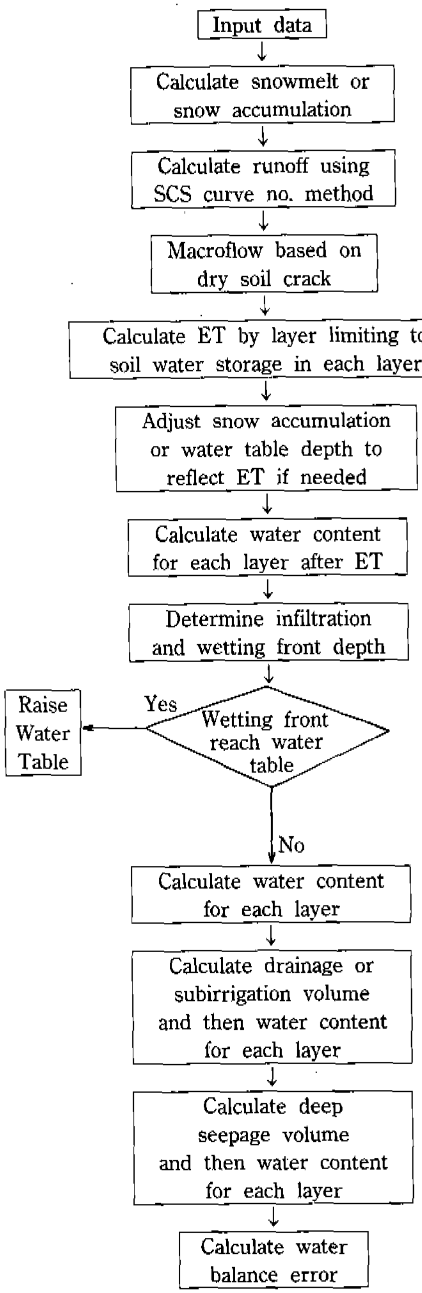


Fig. 1. Flowchart of ADAPT daily hydrologic component

by Dorenbos-Pruitt method. However, the actual ET showed nearly no difference. In this study, the Dorenobs-Pruitt method was used to predict the ET.

To calculate the drainage flow rate, either Kirkham's or Hooghout's equation is used depending on water table condition. When the water table is at the soil surface, Kirkham's equation is used, and when the water table is below soil surface. Hooghoudt's steady state equation is used.

Detailed descriptions of the hydrologic components are shown elsewhere(Chung et al., 1992).

In a previous study(Chung et al., 1992) it is found that surface runoff estimates are very sensitive to changes in curve number, while subsurface drainage flows are very sensitive to deep seepage estimates.

1. Model Inputs and Outputs

To simulate the ADAPT model, several input data are required. They are weather, soil, crop, and drainages system parameters. Weather data include daily rainfall, air temperature, radiation, and windspeed. Soil data are soil texture, thickness of horizons, soil water characteristics, and hydraulic conductivity. Crop data such as effective rooting depth and leaf area index as function of growing stage are required.

Drainage system input parameters include drain depth, spacing, diameter, and depth to impermeable layer. Surface storage depth and SCS curve number CN2 are also required as inputs.

The plant growth in terms of rooting depth and leaf area index is very important in determining evapotranspiration volume. The maximum rooting depth of 0.91m is used. Leaf area index curve for Ohio corn is taken from Knisel(1980).

Output data are monthly sums of surface runoff, subsurface drainage, and combined surface runoff and subsurface drainage volumes. In addition, monthly rainfall, evapotranspiration, deep seepage,

Table 2. Values of major input parameters used in the study

Category	Parameter	Value			
General	CN2	80			
	Surface storage	1 cm			
Soil	Horizon	1	2	3	4
	thickness(cm)	20	30	50	80
	porosity	0.49	0.49	0.47	0.47
	wilting point	0.27	0.27	0.27	0.27
	drainable porosity	0.02	0.02	0.02	0.02
	hydraulic conductivity(cm/hr)	1.37	0.97	0.10	0.08
	impermeable layer conductivity	0.0008 cm/hr			
Crop	Crop	corn(soybean, oat)			
	rooting depth	91 cm			
Tile Drainage System	drain type	concrete pipe			
	drain radius	100 mm			
	drain depth	100 cm			
	drain spacing	1200 cm			
	actural profile depth to impermeable layer	180 cm			
	equivalent profile depth to impermeable layer	165 cm			

and subirrigation volume are output data.

Table 2 shows values of major input parameters used in this study. Though CN2 changes throuthout the year and from year to year, a constant CN2 value is used throughout the simulation period in this study.

IV. Result and Discussions

1. Effects of Drainage System on ET

The seasonal sums(March to September) of rainfall, model predicted ET, and surface and subsurface drainage are shown in Table 3. Fig. 2 shows comparison of Perdicted seasonal sum of ET among different drainage systems. Plots with surface runoff only show the largest average seasonal predicted ET of 52cm, while both plots with tile drainage only and the combined drainage system show nearly the same value of 46cm. This shows that the tile drainage reduces the ET more than 10% by taking the water on or near the soil surface down to the soil profile not subject to the evaporation.

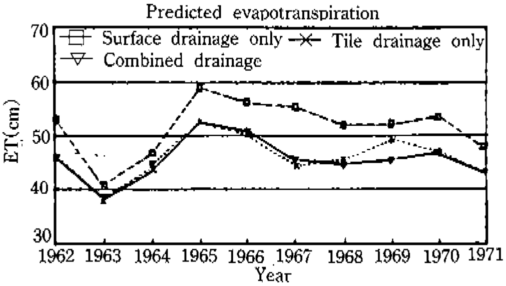


Fig. 2. Comparison of predicted seasonal sum of ET

The small seasonal ET value in 1963 is due to the small rainfall amount as shown in Table 3, while the largest ET in 1965 is due to the large

Table 3. Seasonal sum of rainfall and predicted ET by different drainage systems(cm)

Year	Rainfall	Surface runoff only		Tile drainage		Combined system	
		Runoff	ET	Subdrainage	ET	Total drainage	ET
1962	62.46	11.23	52.77	16.49	46.27	18.58	46.12
1963	46.50	9.15	40.72	15.20	37.74	12.72	38.40
1964	66.01	12.47	46.70	12.88	44.50	16.89	43.56
1965	77.98	15.79	59.06	24.44	52.83	25.61	52.37
1966	89.41	33.45	56.19	37.36	49.85	41.29	50.70
1967	64.41	16.11	55.39	27.35	44.30	26.58	45.41
1968	61.54	12.43	51.95	20.68	45.55	20.90	44.63
1969	92.20	40.30	51.94	38.79	49.07	49.74	45.12
1970	74.09	18.29	53.42	27.14	46.71	27.31	46.40
1971	60.38	14.05	47.56	14.86	43.07	17.80	42.65
Mean	69.50	18.33	51.57	23.52	45.99	25.74	45.54

2. Effects of Drainage System on Drainage Flows

Fig. 3 shows comparision of observed seasonal sum(average of 4 replications) of total outflows. The surface runoff only system gives he smallest total outflow, and the combined surface and tile drainage system gives larger total outflow in general. However, in some years there are only small differences among the three drainage systems.

At the early stage of the 10-year period, the total outflow of tile drainage only and combined drainage systems show nearly the same magnitude while the surface drainage only system show much smaller values. The small total outflow in surface runoff only system might be caused by the deep seepage loss, which could be reduced by and converted to the tile flow in the other systems.

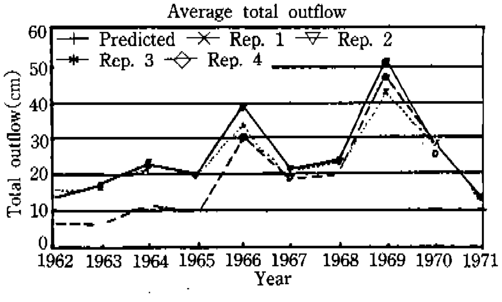
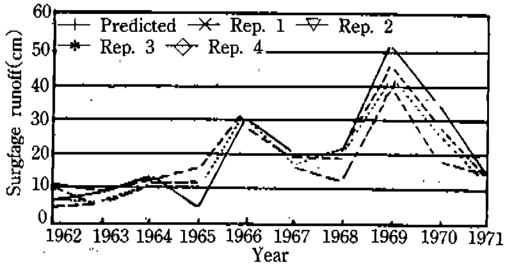


Fig. 3. Comparison of seasonal sum(mean of 4 repication) of total outflow.

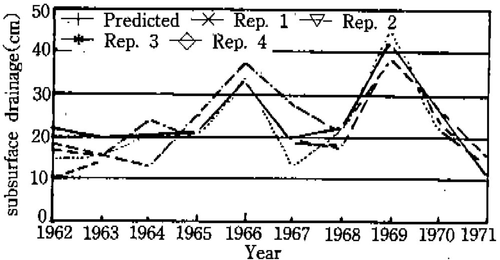
3. Evaluation of the ADAPT Model

To evaluate the ADAPT model, the predicted and observed seasonal sums (March to September) are compared each other. Fig. 4 shows the comparisons of the predicted and observed (4 replications) outflows for the three drainage systems. In some instances there were considerable differences between replications. The observed values for 1966 and 1969 are only approximate because the capacity of the flow monitoring system was exceeded by one severe storm in each of these years.

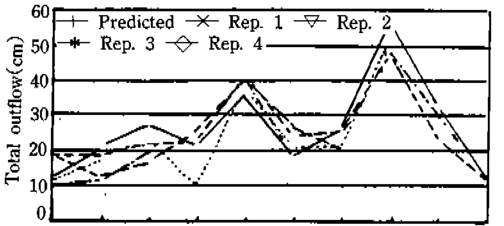
Fig. 4(a) shows the comparison of surface runoff only system. The model underpredicted the runoff volume in years 1968 and 1970. This can be corrected by using a larger curve number CN2 rather than using a constant value throughout the simulation period. In general, model predicted values



(a) surface runoff only



(b) Tile drainage only



(c) Runoff and tile drainage

Fig. 4. Comparison of seasonal sums of observed(4 replications) and predicted values.

are in good agreement with the observed ones considering variations among observed replications.

Fig. 4(b) shows compriosons of seasonal sum of observed and predicted values on the plots with tile drainage only. Tile drainage system shows more variability among repications than the surface only system. In 1964 the model underestimated, while in 1965 to 1967 the model overestimated the observed values. These can be corrected by adjusting the CN2 from year to year. Nevertheless, the model predicted values are in good agreement with the observed ones in general.

Comparison of observed and predicted seasonal sum of combined flow system is plotted in Fig. 4(c). Since the overprediction or underprediction of surface runoff or tile drainage is compensated by each other, the agreement between the predicted and observed values is the best among the three systems.

Some discrepancies might be due to observation errors, while others could be associated with incorrect model input variables as well as the model capability itself. However, considering no calibrated parameters were used in the model evaluation, the predicted values are in good agreement with the observations.

Model input requirements are not excessive and the model gives reasonble estimates of the hydrologic component of water table management system. It can be used in designing water table management systems and does not require extensive calibration.

V. Summary and Conclusions

The effects of drainage system on evapotranspiration and drainage flows in agricultural lands were studied. Data from drainage field experiment at North central Branch, Ohio Agricultural Research and Development Center were used in this study. A water table management model, ADAPT, which was developed by combining the GLEAMS and the subsurface drainiage part of the DRAINMOD model with several modifications, was evaluated and used to predict hydrologic components.

The ET is very much affected by the presence of tile drainage system. The surface runoff only system gives ET values more than 10% higher than the other systems. The combined surface and subsurface drainage system gives the largest total outflow values while the surface drainage only system gives the smallest.

Comparisons of model predicted and observed values of surface runoff only, tile drainage only, and combined surface runoff and subsurface drainage systems are in satisfactory agreement. The absolute errors of combined surface runoff and subsurface drainage system flow were the smallest among the three systems studied. Based on the results of the model evauation study, it is concluded that the ADAPT model can be used to design water table management systems.

Acknowledgement

This study was conducted while the author was on sabbatical leave at the Department of Agricultural Engineering, The Ohio State University. The author would like thank for the financial support of the University.

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