Report for 2004IA64B: Hydrologic Modeling of Subsurface Drainage for Predicting Drainage Outflow.

Publications

- Articles in Refereed Scientific Journals:
    - Singh, R., M.J. Helmers, and Z. Qi, 2006. Calibration and validation of DRAINMOD to design subsurface drainage systems for Iowa's tile landscapes, Agricultural Water Management. (Accepted for publication 5/19/06)
- Conference Proceedings:
    - Qi, Z., M. Helmers, and R. Singh, 2006. Evaluating a drainage model using soil hydraulic parameters derived from various methods. ASAE Meeting Paper No. 062318. St. Joseph, Mich.:ASAE.
    - Singh, R. and M.J. Helmers, 2006. Subsurface drainage and its management in the upper Midwest tile landscape, In Proceedings of the EWRI Congress, ASCE.
    - Helmers, M.J., P. Lawlor, J.L. Baker, S. Melvin, and D. Lemke, 2005. Temporal subsurface flow patterns from fifteen years in north-central Iowa. ASAE Meeting Paper No. 052234. St. Joseph, Mich.: ASAE.

Report Follows

Hydrologic Modeling of Subsurface Drainage for Predicting Drainage Outflow

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Problem and Research Objectives

Movement of water and nutrients through subsurface drainage systems is a concern in many midwestern agricultural watersheds, including the Des Moines Lobe of Iowa. Although subsurface drainage has its benefits—it improves the productivity of croplands and generally reduces surface water runoff—these systems result in a greater volume of subsurface drainage flow to downstream water bodies, thereby increasing nitrate-nitrogen movement to the same. In order to reduce excess water movement and nitrate-nitrogen movement in these watersheds, hydraulic modifications of drainage systems are being considered as water-quality management practices. At the Iowa Water Summit held at Iowa State University on November 24, 2003, three of the five work groups (Nonpoint Sources, Nutrients, and Impaired Water Restoration) identified the need for assessment and demonstration of hydrologic modifications as a new way of addressing water quality concerns, particularly nitrate-nitrogen leaching. Two hydrologic modifications commonly proposed are shallow drain tube installation and controlled drainage. Shallow drainage consists of placing conventional tile drains at shallow depths (e.g., at 24–30" rather than at 48–60"). Controlled drainage raises the outlet of the drainage system at certain times to raise the water table. These modifications to the drainage system are expected to have a direct effect on the volume of subsurface flow and nitrate-nitrogen concentrations and loading from subsurface flow.

However, to evaluate effectively the performance of tile-drained landscapes and potential impacts of modifications, water and nutrient outflow in the system must be accurately estimated or predicted under different scenarios. Use of hydrologic models affords one the opportunity to evaluate the impact of different management strategies on water quantity and quality in subsurface drainage systems; but in order to have confidence in the modeling results, the models should be calibrated and validated. Through calibration and validation the impact of parameters that affect drainage volume—specifically, soil hydraulic properties and climate conditions—can be better understood. With this information in hand, researchers gain confidence in the models' ability to predict subsurface flows and ultimately make use of them in management decisions.

Soil hydraulic parameters are required for running hydrological models. However, it is time-consuming and costly to obtain detailed soil hydraulic parameters in most cases. An alternative way to get these parameters is to use pedotransfer functions (PTFs). Based on artificial neural networks, ROSETTA (Schaap et al., 2001) conducts PTFs to derive van Genuchten soil hydraulic parameters from soil textural data only, combining them with bulk density, or combining soil textural data, bulk density with water content at one or two pressure points (33kPa or 1500kPa).

Van Genuchten soil hydraulic parameters for hydrological modeling could be obtained at different levels when using ROSETTA. One method is to find the soil name, the textural data and bulk density in the maps and tables included in a Soil Survey, then input them into ROSETTA. Another method is to analyze the particle size in the laboratory as well as organic matter content, then to calculate the bulk density and extrapolate θ_{33kPa}, $\theta_{1500kPa}$

by the formula and triangles offered by Rawls (1983) and Rawls and Brakensiek (1983), and input this information into ROSETTA. ROSETTA can use these two levels of information as raw materials and output the van Genuchten soil hydraulic parameters for each data set. Besides those two methods, calibrating the model using non-linear parameter estimation software (PEST) to optimize the initial input hydraulic parameters could be considered as the third level to obtain reliable van Genuchten parameters.

Controlled drainage raises the outlet of the drainage system at certain times to raise the water table and restrict outflow. These modifications have the potential to reduce subsurface drainage volumes, thereby decreasing the export of nutrients and other pollutants from agricultural landscapes. Studies have shown a reduction of 25 to 44% in subsurface drainage through shallow or controlled drainage practices (Evans et al., 1995; Cooke et al., 2002; Sands et al., 2003; Burchell et al., 2003; Fausey, 2004). Since the hydrology of tile landscapes change from one region to another region with variations in weather, soil, and crop cultivation, there is a need to investigate the impact of shallow and controlled drainage considering the local ecohydrological conditions. To better understand the performance of these systems under the climatic and soil conditions present in much of the upper Midwest, a first step is to understand drainage flow patterns over a range of climatic conditions. In addition, for integrating in-field management practices and downstream practices, an understanding of the temporal patterns of drainage flow is useful.

DRAINMOD (Skaggs, 1980), which has been widely applied to modeling the hydrological process of conventional and controlled drainage in the areas with relative high water table, includes the output of ROSETTA as an input of soil hydraulic information. The objectives of this study are to determine which level of soil information would be sufficient to use with DRAINMOD in predicting subsurface drainage volume and to evaluate controlled drainage in reducing drainage over an extended period (1945–2004), using the predicted outflow with a set of soil hydraulic parameters that was proved to be sufficient. This research has applicability in addressing the suitability of models for predicting subsurface drainage and the level of input data required to make accurate predictions. This research is focusing on the drainage outflow, with possible future research in this area to focus on the ability to predict nitrate-nitrogen leaching.

Methodology

Subsurface drainage volumes in five Webster soil plots for 14 years from 1990 to 2003 were simulated using DRAINMOD. The field experimental plots were located near Gilmore City, in Pocahontas County, IA. Drain tiles have been laid at a depth of 1.06 m with a spacing of 7.6 m. The flow rates of all 78 plots and onsite weather have been monitored in the period from April to November since 1989.

DRAINMOD inputs are aggregated into 4 groups: soil, weather, crops, and drainage design. Three different methods were used in preparing the soil hydraulic parameters for the model: 1) determining the soil texture and bulk density(BD) data from the Iowa Soil Properties And Interpretations Database (ISPAID, Version 7.1, 2004), then inputting them into a pedotransfer model (ROSETTA) to determine soil hydraulic properties

(SP_1); 2) analyzing the soil texture and organic matter (OM) content in the laboratory, calculating the BD through the formula offered by Rawls (1983) and extrapolating θ33kpa, and θ1500kpa from the triangle offered by Rawls and Brakensiek (1983), then inputting them into ROSETTA (SP_2); and 3) model calibration with PEST to optimize the soil hydraulic parameters from SP_1 using observed monthly drainage volume from 1990 to 1993 (SP_3).

The detailed description of weather, crop, drainage system design, and monthly ET factors is included in Singh et al (2006). DRAINMOD was run 3 times with soil hydraulic parameters derived from the 3 levels of method and the same weather, crops, and drainage design information. Daily, monthly, and yearly subsurface drainage volumes were collected from DRAINMOD output files. Four statistical measures, as shown in the following, were employed to evaluate the fit of the predicted drainage with the observed data.

$$\text{Root Mean Square Error, } RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(P_i - O_i\right)^2} \tag{2}$$

$$\text{Coefficient of Mass Residual, } CRM = \frac{\sum_{i=1}^{N} P_i - \sum_{i=1}^{N} O_i}{\sum_{i=1}^{N} O_i} \tag{3}$$

$$\text{Index of Agreement, } IoA = 1 - \frac{\sum_{i=1}^{N}\left(P_i - O_i\right)^2}{\sum_{i=1}^{N}\left(\left|O_i - \overline{O}\right| + \left|P_i - \overline{O}\right|\right)^2} \tag{4}$$

$$\text{Model Efficiency, } EF = \frac{\sum_{i=1}^{N}\left(O_i - \overline{O}\right)^2 - \sum_{i=1}^{N}\left(P_i - O_i\right)^2}{\sum_{i=1}^{N}\left(O_i - \overline{O}\right)^2} \tag{5}$$

Simulations of drainage in Webster continuous corn plots with a tile spacing of 30 m and a drain depth of 1.2 m are used to study the drainage patterns over 60 years (1945–2004), using DRAINMOD with a set of soil hydraulic parameters that proved to be sufficient.

Principal Findings and Significance

Soil Hydraulic Parameters

The Webster soil textural data, bulk density, and soil water contents at 2 pressure points are shown in the upper part of Table 1. Since the ISPAID 7.1 only offers the data for the surface soil, the silt and clay content are higher than those obtained from laboratory analysis. However, the bulk density 1.42 g cm^{-3} found in ISPAID is higher than those calculated from Equation (1). Sand content SP_1 is 20% while it is 38%, 33%, and 44% in the top, middle, and bottom layers of Webster soil from laboratorial analysis. In SP_2, the soil in the bottom layer retained higher volumetric soil water content at the two pressure points.

The soil hydraulic parameters for van Genuchten Equation derived from soil parameter input SP_1 and SP_2 by ROSETTA were included in the middle part of Table 1. The difference of these parameters is small except for the saturated hydraulic conductivity and lateral saturated hydraulic conductivity (K_{sat} and LK_{sat}). The K_{sat} in SP_1 is much lower than those in SP_2, which were consistent with bulk density and sand content.

Included in the bottom of Table 1, denoted as Calibration Output SP_3, are the optimized soil hydraulic parameters. After the optimization, K_{sat}, LK_{sat} and α increased to the extent of 1.5 to 2 times while other parameters kept unchanged.

Table 1 Input Soil Parameters and Output Soil Hydraulic Parameters for the 3 Soil Parameter Sets

Input/ Output	Soil Parameter Set	Soil Properties							
		Soil depth	Texture			Bulk density	Θ_{33kPa}	$\Theta_{1500kPa}$	
		(cm)	Silt (%)	Clay (%)	Class	(g cm^{-3})	(cm^3 cm^{-3})	(cm^3 cm^{-3})	
Rosetta Input	SP_1	0-390	49	31	Clay Loam	1.42	-	-	
	SP_2	0-25	33	29	Clay Loam	1.16	0.34	0.18	
		25-50	37	30	Clay Loam	1.19	0.34	0.18	
		50-390	29	27	Loam	1.38	0.35	0.21	
			Soil Hydraulic Parameters						
			q_r	q_s	K_{sat}	LK_{sat} *	■	n	l
			(cm^3 cm^{-3})	(cm^3 cm^{-3})	(cm d^{-1})	(cm hr^{-1})	(cm^{-1})	(-)	(-)
Rosetta Output	SP_1	0-390	0.08	0.43	8.76	0.55	0.008	1.51	-0.24
	SP_2	0-25	0.07	0.49	40.72	2.55	0.022	1.30	-1.11
		25-50	0.07	0.48	32.08	2.01	0.017	1.32	-0.79
		50-390	0.06	0.43	20.5	1.28	0.016	1.33	-0.79
Calibration Output	SP_3	0-390	0.08	0.43	12.96	0.77	0.018	1.51	-0.24

* Lateral saturated hydraulic conductivity is 1.5×Ksat.

14-year Drainage Prediction

Yearly observed and predicted subsurface drainage volume and the statistical measures are included in Table 2. The total predicted drainage in the 14 years with SP_1, SP_2, and SP_3 were 174.5, 176.2, and 182.8 cm, and the total observed drainage volume in Webster soil plots was 179.6 cm. The predicted drainage with parameters from all the 3 methods fitted well with the observed data, and the statistical measures showed little difference. In the years of 1991, 1995, 1997, 1999, and 2001, the drainage flow was over-predicted while it was under-predicted in the years of 1990, 1992, 1996, 1998, and 2002 with any soil parameter set. The predicted flow in SP_3 is higher than SP_1, SP_2, and the observed in general. Although the drainage flow was underestimated by DRAINMOD with SP_1 and SP_2, there is little difference among the 4 statistical measures in the 3 parameter sets. However, it can be concluded that DRAINMOD performed better with data set SP_2 than it did with other sets from the ranking of the statistical measures over the entire 14-year record.

Table 2 Measured and predicted annual drainage with the 3 levels of method and the statistical measures

Year	Measured	Predicted (cm)		
	(cm)	SP_1	SP_2	SP_3
1990	27.24	20.94	23.87	22.73
1991	23.60	25.95	26.04	25.75
1992	17.01	13.33	11.85	13.37
1993	32.80	29.49	31.29	34.72
1994	3.31	4.07	2.64	2.60
1995	3.61	6.40	6.26	6.61
1996	15.37	11.91	11.29	11.03
1997	0.15	3.76	3.64	3.98
1998	8.23	6.71	6.68	6.80
1999	2.03	5.25	5.13	5.87
2000	1.82	2.29	1.58	0.49
2001	13.25	16.38	17.59	18.72
2002	10.34	8.52	6.36	6.32
2003	20.85	19.47	22.02	23.77
Sum	**179.6**	**174.4**	**176.2**	**182.8**
RMSE		3.059	3.055	3.362
Rank		2	1	3
CRM		-0.029	-0.019	0.018
Rank		3	2	1
IoA		0.972	0.975	0.971
Rank		3	1	2
EF		0.907	0.907	0.888
Rank		1	1	2

Statistical measures, based on the monthly predicted and observed drainage during the drainage season, and their ranks are summarized in Table 3. The difference of each statistical measure is small. The calibrated hydraulic parameters (SP_3) performed the best among all three levels of soil parameter sets in predicting drainage volume from 1990 to 1993, since the observed data in these 4 years were used for calibration of SP_3. It was indicated that PEST optimized the hydraulic parameters and gave the best output. However, in the randomly selected validation years of 1994, 1996, 2001, 2002, and 2003, the overall statistical measures for SP_1 and SP_2 were better than those for SP_3.

Although the differences were small among statistical measures for monthly drainage with the 3 sets of soil information, soil parameter set SP_2 performed slightly better than either SP_1 or SP_3 because of its higher stability. In SP_1, five RMSE values in the years of 1990, 1993, 1996, 2001, and 2003 are greater than 2, and three RMSE in the years of 1991, 1994, and 2002 are less than 1; while in SP_2, only three RMSE are greater than 2 and two are less than 1.

The predicted drainage with 3 parameter sets had little difference. In 1991 and 2001, the drainage volume was overestimated. In the wet year 1993, DRAINMOD performs the best with SP_2 in predicting monthly flow. The predicted drainage with SP_3 was consistently higher than that with SP_2 or SP_1 in the year of 1993 and 2001 with a ranking order of drainage prediction of SP_3>SP_2>SP_1.

Table 3 Statistical measures and ranks for monthly predicted and observed drainage volume

Year	N	SP_1				SP_2				SP_3			
		RMSE	CRM	IoA	EF	RMSE	CRM	IoA	EF	RMSE	CRM	IoA	EF
1990	4	2.58	-0.23	0.94	0.78	1.91	-0.12	0.97	0.88	1.62	-0.17	0.98	0.91
1991	7	0.95	0.10	0.99	0.94	0.95	0.10	0.99	0.94	0.76	0.09	0.99	0.96
1992	9	1.42	-0.22	0.91	0.62	1.59	-0.30	0.88	0.52	1.36	-0.21	0.91	0.65
1993	7	2.04	-0.10	0.90	0.69	1.63	-0.05	0.94	0.80	1.58	0.06	0.95	0.81
Overall	**27**	**1.72**	**0.16 ***	**0.95**	**0.82**	**1.52**	**0.14 ***	**0.96**	**0.86**	**1.34**	**0.13 ***	**0.97**	**0.89**
Rank		**3**	**3**	**3**	**3**	**2**	**2**	**2**	**2**	**1**	**1**	**1**	**1**
1994	6	0.51	0.23	0.95	0.83	0.92	-0.20	0.74	0.45	1.16	-0.22	0.54	0.12
1996	6	2.30	-0.23	0.69	0.37	2.47	-0.27	0.64	0.27	2.59	-0.28	0.59	0.19
2001	5	2.08	0.24	0.93	0.71	2.26	0.33	0.92	0.66	2.47	0.41	0.91	0.59
2002	6	0.70	-0.18	0.96	0.87	1.19	-0.38	0.86	0.62	1.15	-0.39	0.89	0.64
2003	4	2.23	-0.07	0.85	0.65	2.60	0.06	0.79	0.53	2.55	0.14	0.82	0.54
Overall	**27**	**1.56**	**0.19 ***	**0.88**	**0.68**	**1.89**	**0.25 ***	**0.79**	**0.50**	**1.99**	**0.29 ***	**0.75**	**0.42**
Rank		**1**	**1**	**1**	**1**	**2**	**2**	**2**	**2**	**3**	**3**	**3**	**3**

* Average over the absolute value of CRM in each year.

An identical ranking order of predicted drainage volume with SP_3 > SP_2 > SP_1 is shown by the daily cumulative drainage volume in Figure 1. The total predicted drainage in the 14 years with SP_1, SP_2, and SP_3 were 174.5, 176.2, and 182.8 cm and the total observed drainage volume in Webster soil plots was 179.6 cm.

In summary, all the 3 levels of data set are proved to be sufficient to run the model. The difference between the drainage outputs is small. It is indicated that ROSETTA in combination with Soil Survey offers a quick and easy way to derive the soil hydraulic parameters. The results also showed that the combination of field soil textural measurements plus ROSETTA (SP_2) performed the best in yearly, monthly, and daily drainage volume prediction though the drainage output differences between SP_2 and two other methods, soil data from soil survey plus ROSETTA (SP_1) and model calibration (SP_3), are small. DRAINMOD showed a higher stability of statistical measures in predicting drainage with soil hydraulic parameters SP_2 than it did with SP_1 or SP_3. SP_2 included more accurate soil textural information, so it achieved a better output than SP_1 did. Even though the soil hydraulic parameters in SP_1 were calibrated by mathematical optimization for obtaining parameters for SP_3, this method (SP_3) did not perform better than the other two methods (SP_1 and SP_2) during the validation years. The procedure of comparing measured and simulated drainage for different levels of soil input information should be performed at other sites to evaluate the level of input soil information that is required to produce reliable predictions of drainage volume. This would be important for using a drainage model for sites where site-specific soil properties may not be available.

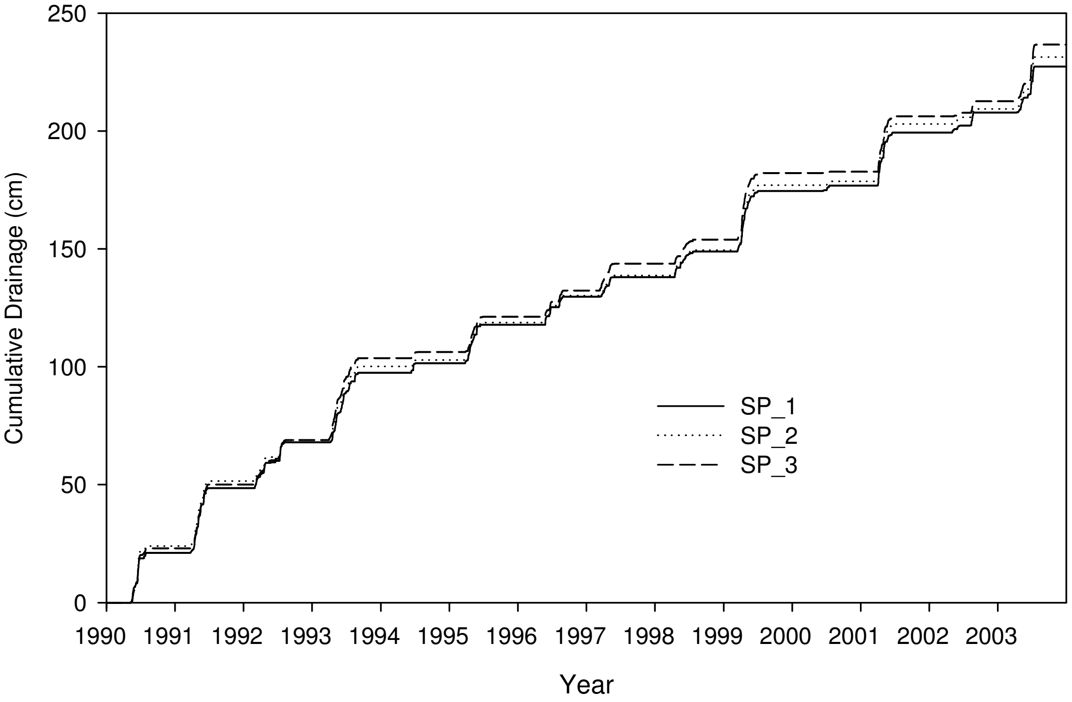

Fig. 1. Daily cumulative drainage volume predicted by DRAINMOD with soil parameter set SP_1, SP_2 and SP_3.

60-Year Drainage Prediction

Soil hydraulic parameters from SP_3 were adopted to simulate the conventional and controlled drainage over the 60-year period. As expected, precipitation and subsurface drainage show variability over the period used in this study. The highest precipitation (119.5 cm) was in 1993 and this also produced the highest subsurface drainage (44.2 cm). While precipitation patterns have a great influence on subsurface drainage, in general there is a correlation between annual precipitation and subsurface drainage (Figure 2). When reviewing the simulation results for this 60-yr period there is a 20% probability of exceeding approximately 20 cm of annual subsurface drainage when the drain spacing is 30 m (Figure 3), and, if the drain spacing was reduced, the drainage volumes are expected to increase.

While Figures 2 and 3 provide an indication of how annual precipitation affects subsurface drainage, precipitation and subsurface drainage patterns throughout the year are important for understanding how drainage management practices or other in-field management practices may be used to reduce the volume of subsurface drainage and subsequently NO_3-N export. In north-central Iowa, the higher precipitation months are from April through August. The higher subsurface drainage months are April and May (Figure 4). While the months of June, July, and August also had similar precipitation as April and May, the crop water use is more in the later months so, as expected, these months have lower volumes of subsurface drainage (Figure 5). This highlights that the periods of higher subsurface drainage occur when there is little vegetative growth on the landscape in a corn-soybean agricultural system. This also coincides with periods when subsurface drainage is important for trafficability and early crop growth. By the end of May, on average, approximately 60% of the annual subsurface drainage has occurred and by the end of June nearly 80% of the annual subsurface drainage has occurred. The months of April and May alone account for nearly 45% of the annual subsurface drainage. Reviewing just the months of April, May, and June there is a 20% probability of exceeding 5 cm of subsurface drainage in each of these months (Figure 6).

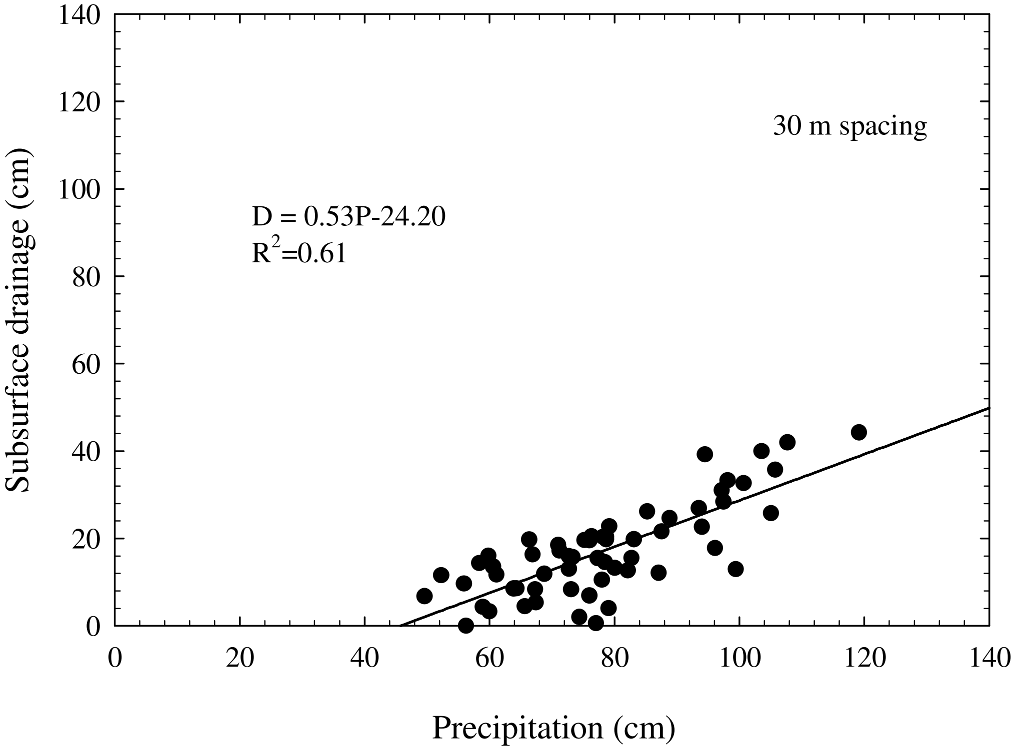

Fig. 2. Correlation between annual precipitation (cm) and simulated subsurface drainage (cm) over the 60 years (1945–2004).

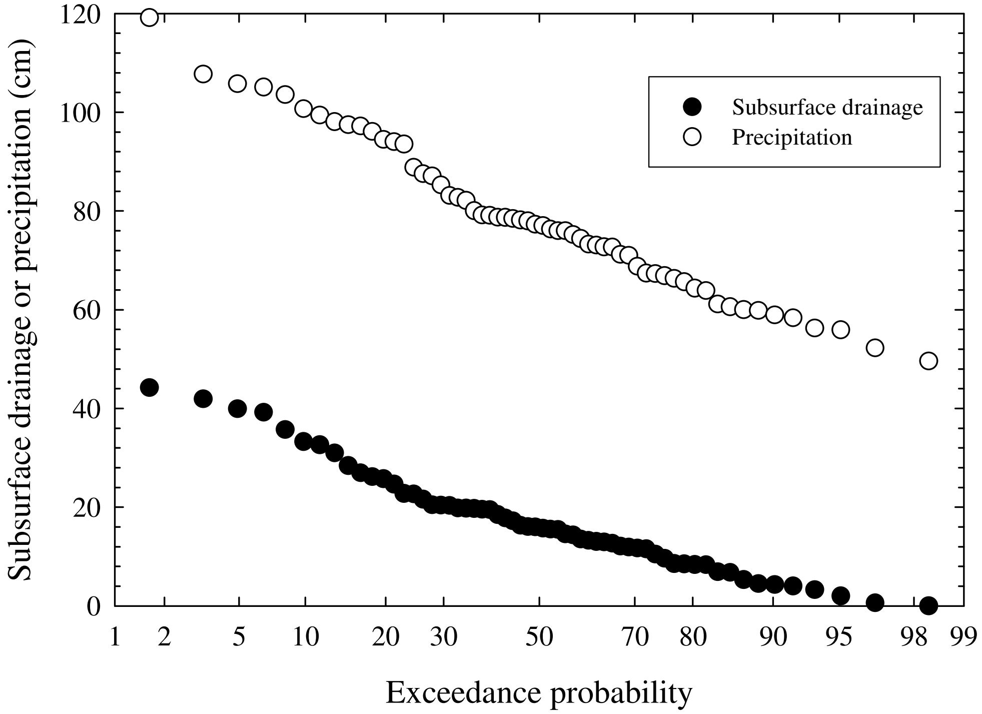

Fig. 3. Exceedance probability of annual precipitation (cm) and subsurface drainage (cm) over the 60 years (1945–2004).

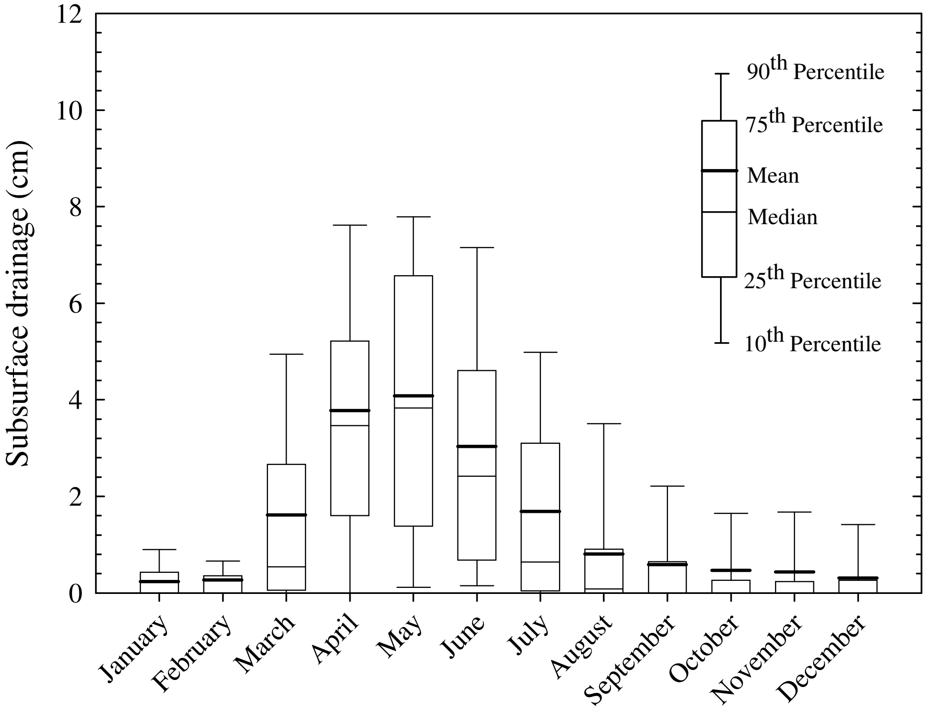

Fig. 4. Distribution of monthly simulated subsurface drainage (cm) over the 60 years (1945–2004).

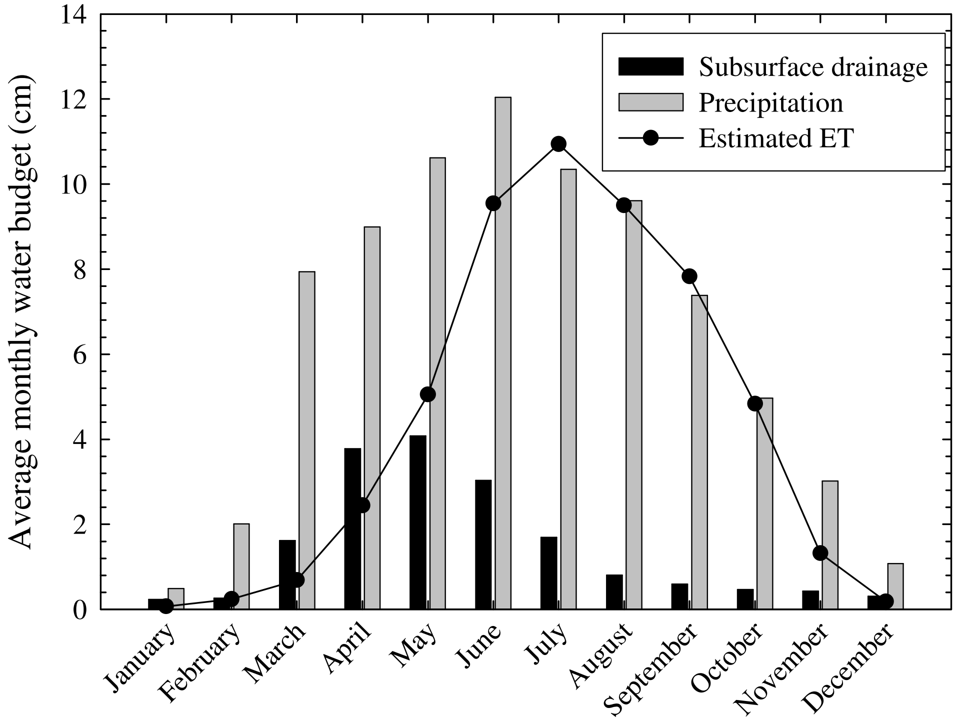

Fig. 5. Average monthly water budget (cm) over the 60 years (1945–2004).

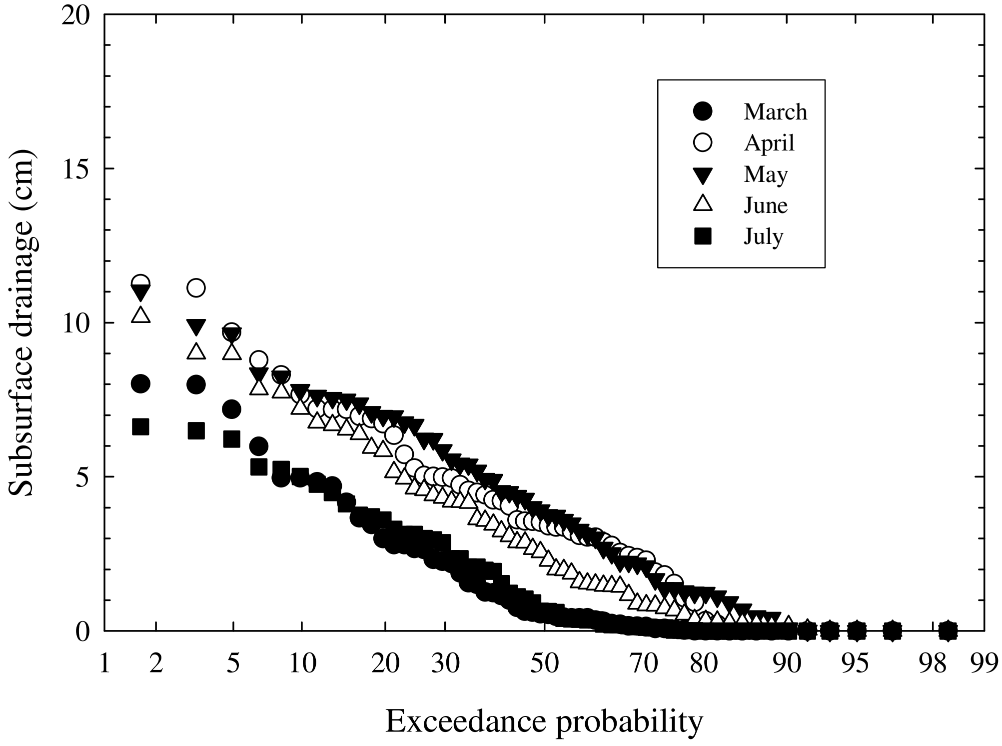

Fig. 6. Exceedance probability of average monthly subsurface drainage (cm) for specific months (from March to July) over the 60 years (1945–2004).

One drainage management practice being considered for reducing the volume of subsurface drainage is controlled drainage where the outflow of the subsurface drainage system is controlled during specific months of the year when maximum drainage is not required. Maximum drainage is required for trafficability during crop sowing (April and May) and harvesting (September and October) months. Using DRAINMOD, controlled drainage was investigated by controlling subsurface drainage outflow during the months of November through March and then again from June through August. During these months the drain outflow was restricted to maintain a depth of 60 cm below the ground surface, while free drainage at a normal outflow depth of 120 cm was used during the months of April, May, September, and October. Simulated average monthly subsurface drainage and surface runoff for conventional (free drainage) and controlled drainage over the 60 years (1945–2004) are shown in Figure 7. Since the months of April and May are time periods when both the conventional and controlled drainage systems have free drainage outflow at the normal outflow depth of 120 cm, there is no reduction in subsurface drainage in these months for the controlled drainage system. In fact, since water has been stored in the soil profile during the winter months and then released when the outflow level is lowered to free drainage level, there is an increase in subsurface drainage in April and May under the controlled drainage system. During the months when the outflow level is controlled to 60 cm there is a reduction in subsurface drainage with the controlled drainage management. However, much of this reduction is reflected in increased surface runoff (Figure 7).

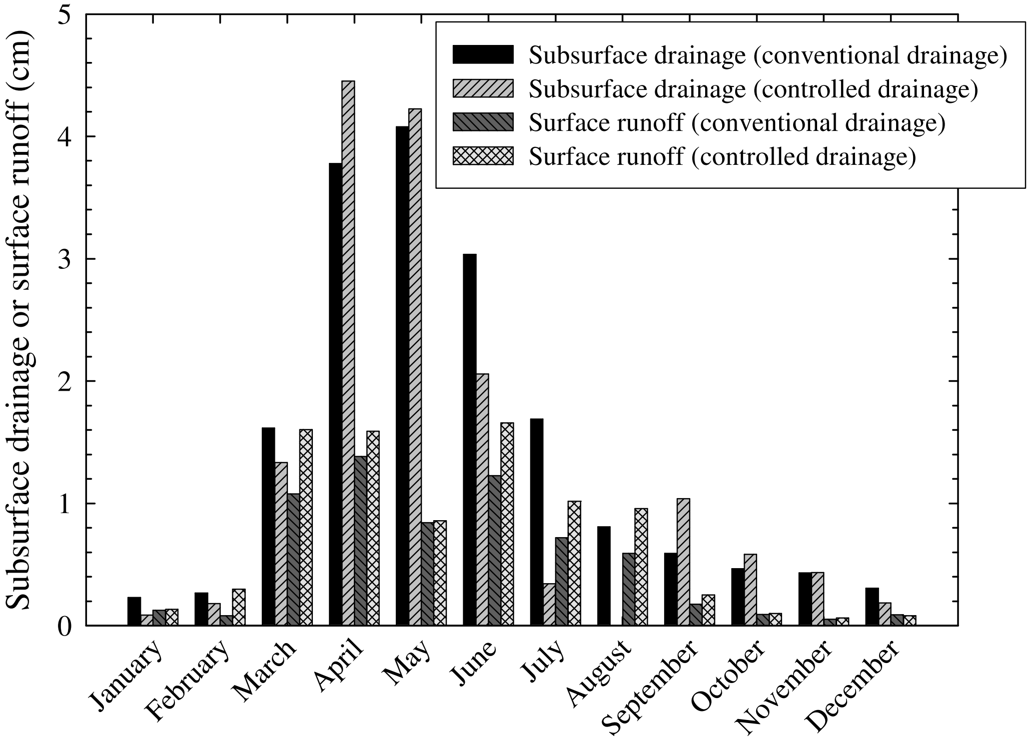

Fig. 7. Simulated average monthly subsurface drainage (cm) and surface runoff (cm) for conventional (free drainage) and controlled drainage systems over the 60 years (1945–2004).

The simulated annual subsurface drainage is reduced when using a controlled drainage management system (Table 4). However, as mentioned above, most of this reduction is reflected in increased surface runoff. There is approximately a 16% reduction in subsurface drainage and a 33% increase in surface runoff. When reviewing the exceedance probability for subsurface drainage and surface runoff for the controlled and conventional drainage, the controlled drainage consistently reduces the volume of subsurface drainage while increasing the volume of surface runoff (Figure 8). It must be noted that these simulations accounted for little vertical seepage as would be expected in north-central Iowa. From an intensive groundwater modeling study, Ella et al. (2002) estimated 2.3 to 4.3% of the annual precipitation as groundwater recharge in the glaciated region of the Des Moines Lobe, IA. Also, the simulations did not include lateral seepage that may occur in some controlled drainage situations so there is the possibility that there could be an increased reduction in subsurface drainage and less increase in surface runoff from controlled drainage when accounting for lateral seepage. The simulations showed little change in the estimated ET (Figure 9) but there is the possibility that ET could be increased under certain controlled drainage scenarios if there is water stored within the soil profile during the summer months. This possibility warrants additional investigations. These simulations show smaller reductions in the volume of subsurface drainage than many field investigations in other parts of the U.S have shown (Evans et al., 1995; Cooke et al., 2002; Sands et al., 2003; Burchell et al., 2003; Fausey, 2004). From this there is a need to study the performance of controlled drainage on a field-scale in Iowa and specifically account for the pathways of water movement.

Table 4 Simulated average annual subsurface drainage (cm) and surface runoff (cm) for conventional (free drainage) and controlled drainage systems over the 60 years (1945–2004).

	Subsurface drainage (cm)	% Reduction	Runoff (cm)	% Reduction
Conventional drainage	17.29		6.45	
Controlled drainage	14.54	15.9	8.59	-33.2

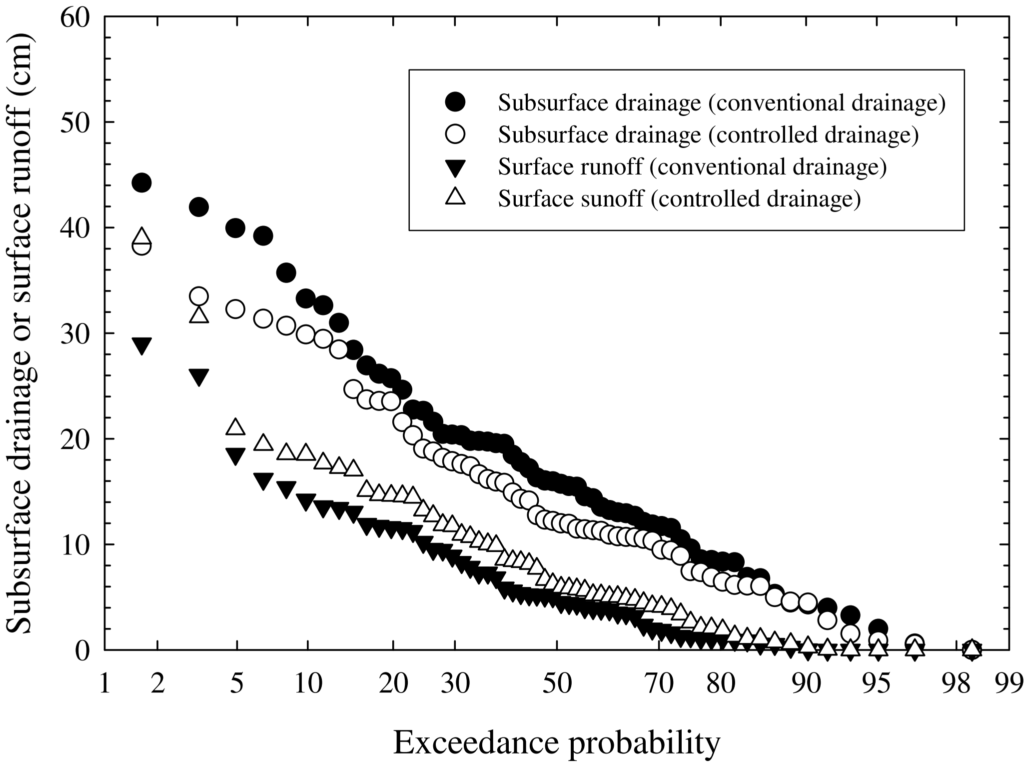

Fig. 8. Exceedance probability of simulated annual subsurface drainage (cm) and surface runoff (cm) for conventional (free drainage) and controlled drainage systems over the 60 years (1945–2004).

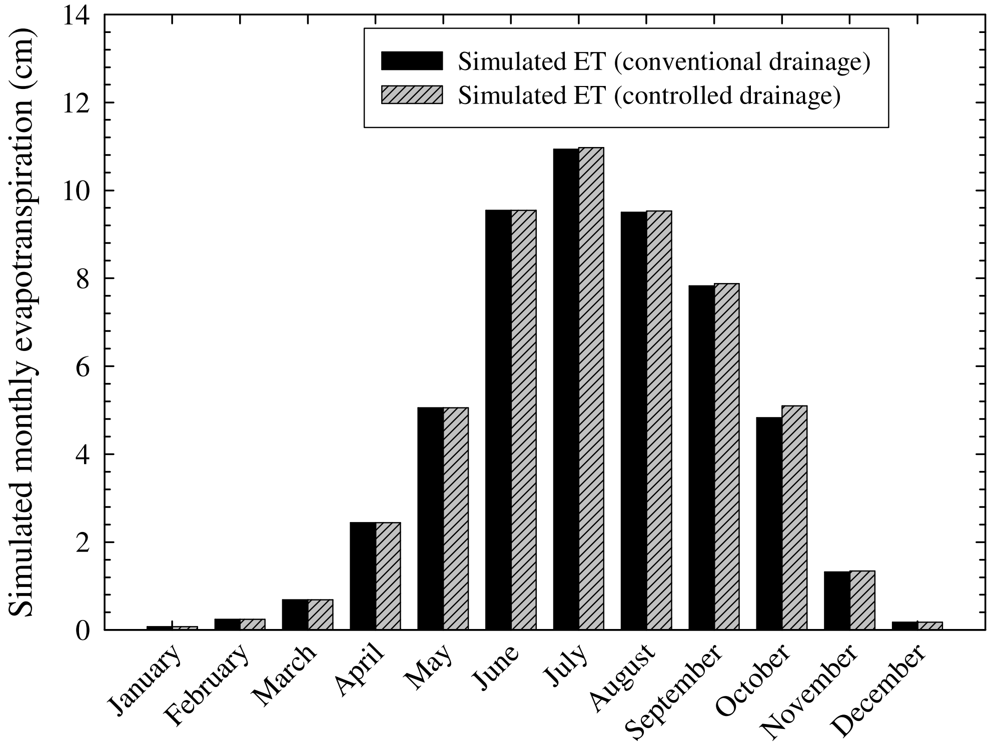

Fig. 9. Simulated average monthly evapotranspiration (cm) for conventional (free drainage) and controlled drainage systems over the 60 years (1945–2004).

From the analysis of precipitation, conventional and controlled drainage prediction, we found that approximately 45% of the annual subsurface drainage occurs in the months of April and May and approximately 80% of the annual subsurface drainage has occurred by the end of June. This coincides with the time when maximum drainage is required for trafficability and crop development specifically during the months of April and May. This coincident may limit the effectiveness of drainage management practices such as controlled drainage to reduce subsurface drainage in north central Iowa. When simulating controlled drainage where the outflow was controlled during the winter months (November to March) and the summer months (June to August), there was approximately a 16% reduction in the volume of annual subsurface drainage but most of this reduction was reflected in increased surface runoff. So, while controlled drainage has some potential to reduce subsurface drainage it would need to be managed so that any negative impacts of potential increases in surface runoff are considered. In addition to drainage water management practices there is a need to consider and study other management practices that could be used to reduce subsurface drainage specifically during the early spring months when there is little water use by the common corn-soybean agricultural system. Alternative cropping practices such as cover crops and living mulches are two potential practices that might increase water use during this time period. These practices may also use some of the available nitrate within the soil profile so that there is less risk of nitrate loss. There is a need for further study of subsurface drainage water management practices in the tile-drained landscapes of Iowa and the upper Midwest of the U.S. along with studies that investigate the potential for using cropping practices that may also have a positive effect on subsurface drainage and nitrate export.

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