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TILLAGE AND CROP ROTATION EFFECTS ON SUBSURFACE DRAINAGE RESPONSE TO RAINFALL

D. L. Bjorneberg, R. S. Kanwar, S. W. Melvin

ABSTRACT. *A field study was conducted to determine if tillage and crop rotation affected subsurface drainage response to rainfall. An instrumentation system collected subsurface drain flow data from thirty-six, 0.4 ha plots during the 1993, 1994 and 1995 growing seasons. Response time, time-to-peak drain flow rate, drainage volume, peak drain flow rate and percent preferential flow were compared between two tillage systems (no-till and chisel plow) and two crop rotations (continuous corn and corn-soybean) for 23 drainage events over the three-year study. The influence of preferential flow was estimated for each drainage event using a hydrograph separation procedure based on subsurface drain flow rate changes.*

Drainage event parameters were not consistently different between crop and tillage systems during this study. Drainage parameter data were highly variable and little correlation was observed between parameters. Percent preferential flow was found to be greater than 10% of the total subsurface drain flow only four times for the 23 drainage events. The highest average percent preferential flows for an event did not correlate with the highest rainfall intensity and varied among crop and tillage systems. Annual averages of drainage parameter data indicated that drainage volume and peak drainage rate may have been influenced more by the experimental plot than by the crop. Overall results indicated that changes occurring in the soil flow system during the growing season may have more influence on preferential flow and subsurface drain flow compared to tillage and crop rotations for these loam soils.
Keywords. *Preferential flow, Hydrograph separation.*

Water does not flow uniformly though soil, but through least resistant pathways as noted by Beven and Germann (1982), Booltink and Bouma (1991), Gish and Jury (1983), Kanwar (1991), Kluitenberg and Horton (1990), Kung (1990), Priebe and Blackmer (1989), Richard and Steenhuis (1988), and others. Sudden increases in subsurface drain flow rates immediately after heavy rains have been observed in agricultural fields and are considered to be due to preferential flow. The preferential pathways may be cracks, root holes, worm burrows or pore spaces between soil particles. These flow paths, however, can change with crops, tillage, climate and time. Singh and Kanwar (1991), for example, found larger diameter and better-connected macropores in no-till soil compared to conventionally tilled soil. Also, no-till soil tends to have more earthworms and earthworm holes than tilled soil (Dick et al., 1991; Ehlers, 1975).

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Monitoring subsurface drainage for water quality studies is useful because the drains integrate effects of preferential and matrix flows (Richard and Steenhuis, 1988). Separating water flow to subsurface drains into two components was first described by Lawes et al. (1882) as direct drainage and general drainage. Everts and Kanwar (1990) measured tracer concentrations in subsurface drains and assumed a dual porosity system to estimate the preferential flow contribution to subsurface drainage during a rainfall simulation. Steenhuis et al. (1994) also assumed water flowed through two distinct pathways to develop an equation for predicting preferential flow solute concentrations. While preferential flow (direct drainage) and matrix flow (general drainage) are actually on opposite ends of a continuum, a dual porosity model seems to describe the system better than a uniform porosity model.

Three typical drain flow measurement systems are (1) weirs or flumes with stage recorders; (2) sump pumps with flow meters; and (3) tipping buckets (Milburn and MacLeod, 1991). Only weirs and flumes collect continuous subsurface drain flow data. Both tipping buckets and sump pumps collect data at discrete flow intervals. A certain volume of water is required to tip the bucket or activate the pump. The precision of these systems is determined by the size of the bucket or sump. One advantage of a sump pump system, however, is that water does not have to flow by gravity from the sump to an outlet as with weirs, flumes or tipping buckets.

A subsurface drainage monitoring site was established in 1990 for determining crop and tillage impacts on groundwater quality (Kanwar, 1991). The objective of this study was to use three years of data (1993 to 1995) from this site to determine crop rotation and tillage effects on subsurface drain flow response to rainfall. The four parameters identified for each drainage event were response time, time-to-peak drain flow rate, drainage volume, and peak drain flow rate. A simple method for estimating the influence of preferential flow on subsurface drain flow was also used for comparing drainage response to rainfall.

MATERIALS AND METHODS

EXPERIMENTAL SITE

The experimental site for this study was Iowa State University's Northeast Research Farm near Nashua, Iowa. The primary soil types, Floyd, Kenyon, and Readlyn loams, have loamy topsoil with loam, clay loam, and sandy loam subsoil. Floyd and Readlyn soils are somewhat poorly drained while Kenyon soil is moderately well-drained. Slopes vary from 0 to 4%, but are generally less than 2%.

Farming practices on the thirty-six, 0.4-ha plots included 12 no-till (NT) and 18 chisel plow (CP) plots under corn-soybean rotation and 6 continuous corn (CC) chisel plow plots (fig. 1). Chisel plow plots were plowed in fall and field cultivated in Spring before planting. No-till crops were planted directly into stubble. All soybean plots were planted with a no-till drill and were not cultivated for weed control. The NT treatment was not a true no-till system because all corn plots were cultivated once for weed control, except in 1993 when wet conditions prevented this cultivation.

Three different nitrogen fertilizer treatments were used. CC plots received either a pre-plant application or a fall manure application. CP rotation corn received a pre-plant application, a fall manure application or a pre-plant application with additional fertilizer sidedressed in June based on a late spring soil nitrate test. NT rotation corn received the same nitrogen treatments as CP rotation corn except the manure treatment.

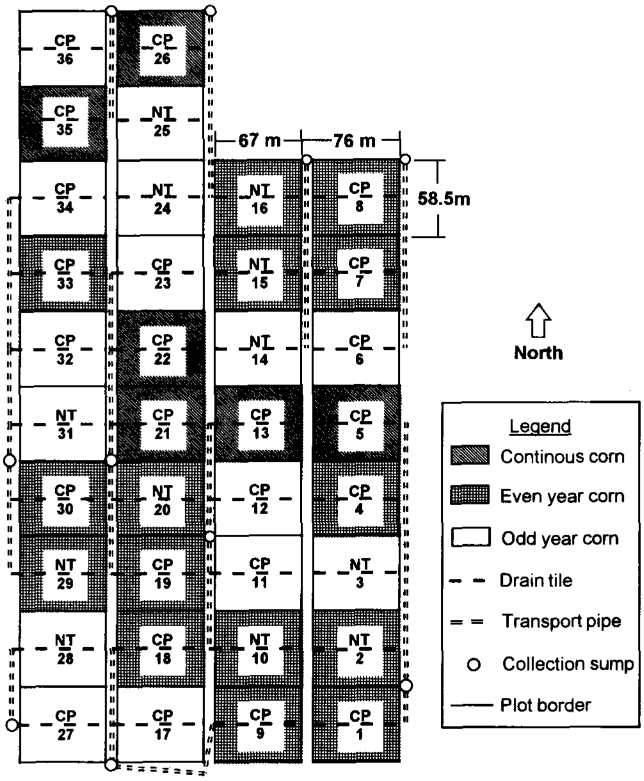

Figure 1–Plot layout at the Nashua Water Quality site.

SUBSURFACE DRAINAGE SYSTEM

As shown in figure 1, one-hundred-mm-diameter, corrugated plastic, subsurface drains were installed approximately 1.2 m deep at 28.5 m spacing in 1979. Drains were located in the centers of the plots and on the borders between plots. In 1989, the center drains were intercepted for drain flow measurements and water quality sampling. The drains along the plot borders isolate the north and south sides of the plots. The plots were not isolated on the east or west sides. Center drain lines were routed to individual meter sumps at one of 10 collection sites. The collection sites were located so water flowed by gravity from the plot to the meter sump. Each collection site had 2- to 6-m sumps (fig. 1). The meter sumps were 0.4-m diameter PVC air duct tubing with sealed bottoms. Inside each meter sump was a flow metering assembly which included a 0.37-kW sump pump, check valve, flow meter, and quick release coupler (fig. 2). A 38-mm diameter PVC pipe connected the sump pump to a spring-type check valve and the check valve to a positive displacement water meter.

Water pumped from the meter sump flowed through a 25-mm flow meter to a collection sump, which was a 0.6-m diameter corrugated black plastic culvert. An overflow pipe with check valve allowed water flow to the collection sump if the sump pump malfunctioned. Water-tight seals were used on all lower connections to the meter sumps to ensure a good seal against groundwater seeping into the sumps. Water in collection sumps was discharged by gravity to an outlet tile (fig. 2). Approximately 40 L of water were discharged from a given sump during a pump cycle, which approximately equals 0.02 mm of drainage from the plot.

SUBSURFACE DRAIN FLOW MEASUREMENT

Flow meters have cast bronze cases and nutating disc measuring chambers, which measure volume by the positive displacement principle. Each flow meter had an analog register and electronic transmitter. The analog register recorded total drain flow to 0.001 m^3 while the

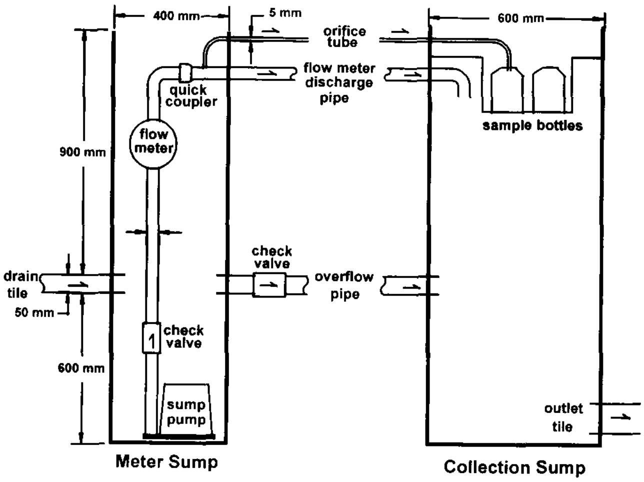

Figure 2–Schematic diagram of meter sump and collection sump.

output voltage from the electronic transmitters indicated when the sump pump was running.

Total drain flow was recorded manually three times per week during 1993 and twice a week during 1994 and 1995. Sump pumps and flow meters were removed from the field after drains stopped flowing in the winter (usually mid-December). Flow meters were calibrated in the shop each winter by comparing the measured volume with the actual volume pumped through each meter.

Data loggers monitored the output voltage from the electronic transmitters and recorded rainfall with tipping bucket rain gage. Transmitter output voltage was measured at one second intervals by the data loggers to determine when each sump pump was operating. By recording the times when sump pumps started and stopped pumping, the duration of the pump cycle was determined. The data loggers were essentially used as timers to measure how long a sump pump operated during a pump cycle and the time interval between pump cycles.

The pumping rate for each sump pump was calculated by dividing the total volume of water pumped (measured with the analog meters) by the total pumping time (measured with the data loggers). Calculated pumping rates for each interval between flow meter readings were averaged during June 1993 to give an average pumping rate for each sump pump. The volume of water discharged during a pump cycle could then be calculated by multiplying the duration of the pump cycle by the average pumping rate for the sump pump. Drain flow volume calculated from data logger information was periodically compared to the volume measured with the analog meters to ensure that the system was operating accurately (fig. 3).

A constant volume of water was not discharged during each pump cycle due to varying inflow rates. The volume of water discharged during a pump cycle was usually about 40 L but increased to over 100 L at high drain flow rates (0.8-1.0 L/s). The volume of water discharged during a pump cycle equals the volume of water that drained from the plot since the previous pump cycle. Drain flow rates were calculated by dividing the volume of water discharged during a pump cycle by the time interval since the previous pump cycle.

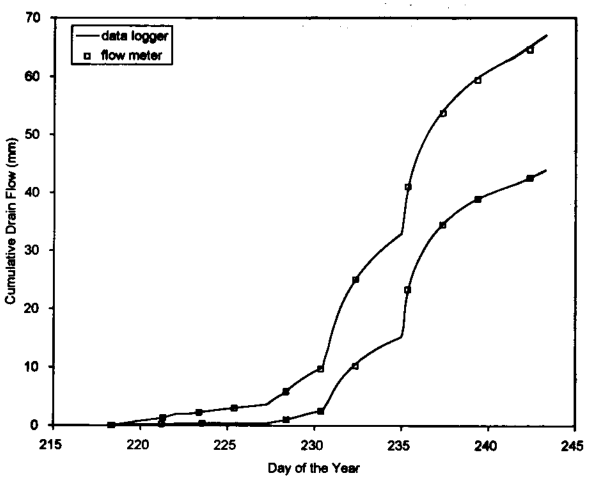

Figure 3–Cumulative drain flow measured by data loggers and flow meters for two no-till soybean plots during August 1993.

Drainage Parameters

Drainage events were characterized by a rapid increase in drainage rate followed by a slower recession. Similar drainage response to rainfall was described by Lesaffre and Zimmer (1988). The beginning of a drainage event was defined as the time when drain flow rate starts increasing in response to rainfall. The event presumably ended when the next drainage event began or the drainage rate decreased to the pre-event rate.

The four parameters determined for each drainage event included response time, time-to-peak drain flow rate, drainage volume, and peak drain flow rate. Response time was the time interval between the first tip of the rain gage (0.25 mm of rain) and the beginning of a drainage event. Time-to-peak was the time interval between the start of the drainage event and the peak drain flow rate. Drainage volume was the total drain flow that occurred during the event and peak drain flow rate was the highest drain flow rate calculated for the event.

The amount of drain flow resulting from preferential flow during a rain event was estimated by a hydrograph separation technique. The variable slope method for separating stream hydrographs into baseflow and surface runoff components (Chow et al., 1988) was adapted for determining the relative contributions of matrix and preferential flow to drain discharge. The matrix flow rate was assumed to be relatively constant during a drainage event, similar to baseflow for a stream hydrograph. Rapid drain flow rate changes were assumed to be caused by preferential flow, analogous to surface runoff. The analogy between surface runoff and preferential flow is not completely valid since most preferential flow paths are not directly connected to subsurface drains. Theoretically, the preferential flow portion of drain discharge results from changes in hydraulic head as water flow preferentially through the soil. Hydraulic head increases rapidly as infiltrating water flows vertically through preferential flow paths while air is trapped in the remaining soil matrix. The drain flow rate decreases quickly as water in the preferential flow paths spreads to the soil matrix and air leaves the soil. The redistribution of water causes the matrix flow portion of drain discharge to increase. The matrix flow rate continues to increase until the matrix and preferential hydraulic heads are equal. The reasoning behind this preferential flow separation method may not be true with nature but it characterizes the rapid drainage rate changes that result from rainfall.

Drain flow rates were normalized for each event to eliminate differences in peak flow rates among events and plots. Rates were normalized by dividing the rate for each time interval by the peak rate for the event. To determine when preferential flow was occurring, the change in drainage rate with time was calculated for each drainage event. These rate changes were used to divide hydrographs into three segments (fig. 4). Point A indicates when the drainage event began. Point B signifies the inflection point on the drainage rate change curve while point C is the time when the rate change becomes almost constant.

Normalized drainage rate changes were consistent among almost all plots and drainage events. Drainage rate increased rapidly at the beginning of a drainage event. After the peak rate occurred, flow decreased rapidly for a short time before decreasing at a slower, almost constant

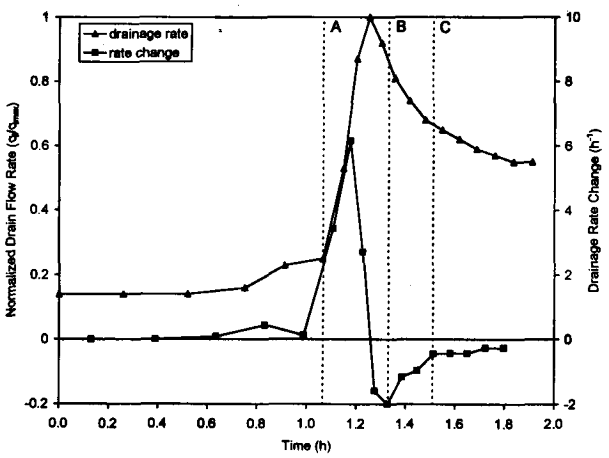

Figure 4–Normalized drain flow hydrograph separated according to drainage rate changes for event 5a (1993).

rate. Matrix flow was assumed to continue at a constant rate between points A to B and then increase linearly between points B and C, because these are the simplest relationships to use. Preferential flow accounts for the rapid increase and decrease in drainage rate. After point C, preferential flow presumably stops and matrix flow accounts for the entire drain flow (fig. 5).

After identifying points A, B, and C for each drainage event, the volume of matrix flow between points A and C was calculated by the following equation:

$$Q_m = q_A(t_B - t_A) + (1/2)(q_C + q_A)(t_C - t_B) \quad (1)$$

where Q_m is matrix flow volume; q_A and q_C are drainage rates at points A and C respectively; and t_A, t_B and t_C are time at points A, B, and C, respectively. The preferential flow volume and percent preferential flow were then calculated by the two following equations:

$$Q_p = Q_{AC} - Q_m \quad (2)$$

$$\%Q_p = 100(Q_p)/Q_T \quad (3)$$

where Q_p is preferential flow volume, Q_{AC} is total flow between points A and C, and Q_T is total flow for the

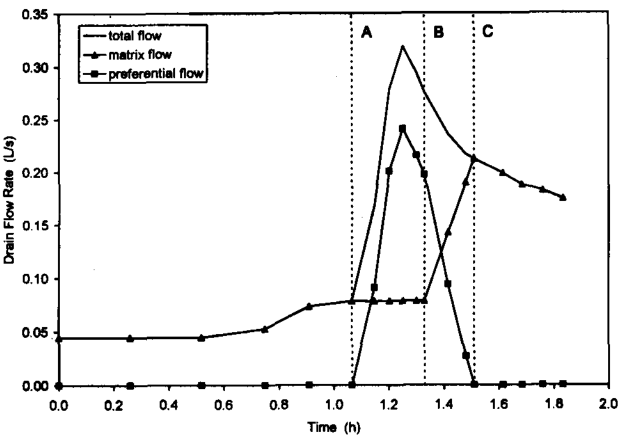

Figure 5–Separated drain flow hydrograph showing preferential and matrix flow components for event 5a (1993).

drainage event. Figure 5 shows a separated hydrograph for event 5a in 1993.

For some drainage events, point B could not be identified because the drainage rate for some plots did not decrease rapidly. Under these circumstances, The matrix flow rate was assumed to increase linearly from points A to C. Matrix flow volume was then calculated by equation 4 instead of equation 1.

$$Q_m = (1/2)(q_C + q_A)(t_C - t_A) \quad (4)$$

If hydrographs from two rainfall events overlapped, preferential flows from both events were combined. Preferential flow volume was calculated for each event as previously described. The volumes from each event were summed and divided by the total drainage for both events to give the percent preferential flow over both events. Point A from the second event never occurred before point C from the first event.

Data Analysis

Drainage parameter data were averaged by crop and tillage system for each drainage event without regard for nitrogen management practices. Five different systems were considered in this study: chisel plow continuous corn (CC); chisel plow rotation corn (CP-corn); no-till rotation corn (NT-corn); chisel plow rotation soybean (CP-bean); and no-till rotation soybean (NT-bean). Rotation corn and rotation soybean were the corn and soybean phases of the corn-soybean rotation, respectively. The number of plots averaged within a system was not constant due to periodic equipment malfunctions. Since the data were not normally distributed (skewed to the right), nonparametric statistical analysis was used. Wilcoxon's signed-rank test for paired differences (Snedecor and Cochran, 1989) was used on event averages to compare differences on an annual basis and over the three-year study ($p = 0.05$). This test is the nonparametric equivalent of a paired T-test. Ten tests were used for each parameter to compare all combinations of the five crop and tillage systems on an annual basis or over the three-year study.

Results and Discussion

Several equipment and operational problems occurred in 1993. Excessive rain resulted in high subsurface drain flows and large amounts of stored data in data loggers; occasionally exceeding the storage capacity of the data loggers within 24 h. Some wires had also been cut, broken or corroded in the three years since installation. If there were any questions whether or not equipment problems caused erratic data, the data were not included in the analysis. Reliable data were available from only 18 of the 36 plots in 1993 (three NT-bean, four CP-bean, three NT-corn, five CP-corn, and three CC). After equipment repair and data logger program modifications in 1993, the reliability of data collection increased. Unsolved problems with buried wires for seven plots continued during 1994 and 1995. Consequently, drain flow data were available for 29 plots during 1994 and 1995 (six NT-bean, seven CP-bean, four NT-corn, six CP-corn, and six CC).

Precipitation during the 1993 growing season was 1000 mm, approximately 250 mm above the growing season average for the site. The extremely wet conditions caused subsurface drains to flow almost continuously during the entire growing season. Five drainage events were identified as a result of rainfall greater than 25 mm. Four of these events were sub-divided because drainage rates changed as rainfall intensity varied; increasing the total number of 1993 drainage events to 10 (table 1). In addition to being extremely wet, 1993 was a transition year for the site. Before 1993, one NT-bean plot had been moldboard-plowed, one CP-bean and two CP-corn plots had been ridge-tilled, and two CP-corn plots had been moldboard-plowed.

Precipitation during the 1994 growing season was close to the normal precipitation of 750 mm. Drains flowed sporadically during the growing season and six drainage events were identified to be used in this analysis. A linear-move irrigation system was used to apply approximately 20 mm of water on 18 through 20 October for the sixth event (table 1). The system moved from north to south across two plots at a time. The two west rows of plots (plots 17-36) were irrigated first (fig. 1). Events 5 and 6 occurred after harvest and before fall tillage.

Subsurface drains also flowed sporadically during 1995 when precipitation was again close to normal. Seven drainage events were identified (table 1). The maximum rainfall intensities were less than 10 mm/h for the first three events. The remaining events had maximum intensities of 64 to 230 mm/h. Peak drain flow rate exceeded the pumping rate for six plots during events 4 through 7. This caused the sump pumps to run continuously for up to an hour, cutting off the peaks of the drain flow hydrographs. Time-to-peak and peak drain flow rate data from these six plots were not used for events 4 through 7.

Three example drain flow hydrographs show the variability in drain flow response to rainfall (figs. 6, 7, and 8). Plots 4 and 11 were both chisel plow, corn-soybean rotation plots. Plot 4 was planted to the corn phase of the rotation in 1994 while plot 11 was planted to corn in 1993 and 1995. Three high intensity rains caused multiple responses for event 5 of 1993 (fig. 6). A similar intensity rain during event 1 of 1994 did not cause the drain in plot 4 to flow (fig. 7). The drain flow rates for plot 11 were also lower due to drier conditions. The low intensity rain during event 2 of 1995 caused a much slower response than the previous examples (fig. 8). Notice that plot 11 had higher drain flow rates than plot 4 for all three events regardless of the crop that was planted.

Drainage parameter values were extremely variable between drainage events because of differences in soil moisture, crop cover, rainfall intensity, etc. Response times

Table 1. Date, duration, depth, and maximum intensity of rain for drainage events

Event	Event Beginning Date	Event Beginning Time	Duration (h)	Rainfall Depth (mm)	Maximum Intensity (mm/h)	Previous Rain
			1993			
1	29 June	18:56	12.3	30	23	2.5 mm on 19 June
2a	08 July	20:26	1.1	5	7	9 mm on 5 July
2b	08 July	21:32	5.9	46	19	
3a	15 Aug	5:41	4.3	27	84	11 mm on 14 Aug
3b	16 Aug	2:38	5.3	12	9	
4a	18 Aug	10:04	2.9	30	91	Event 3b
4b	18 Aug	17:46	1.9	10	46	
5a	22 Aug	23:02	0.7	24	107	8 mm at 6:00, 22 Aug
5b	23 Aug	0:11	0.7	11	91	
5c	23 Aug	2:33	4.0	21	103	
			1994			
1	19 June	16:07	2.4	24	94	6 mm in past 5 days
2*	07 July			41		9 mm in past 14 days
3*	13 July			25		23 mm on 12 July
4*	19 July			25		9 mm on 18 July
5	17 Oct	14:37	5.8	17	30	10 mm at 3:00, 17 Oct
6†	18 Oct		2.0	20	64	Event 5
			1995			
1	11 April	10:09	9.2	13	8	11 mm on 10 April
2	02 June	3:54	7.8	10	9	13 mm on 1 June
3	06 June	20:10	5.8	13	10	11 mm on 5 June
4	25 June	12:40	8.3	40	64	25 mm on 24 June
5	26 June	14:03	2.4	22	114	Event 4
6	04 July	18:27	4.5	42	152	2 mm 12 h earlier
7	05 July	12:22	1.9	17	230	Event 6

* Unreliable information from data logger recording rainfall, only total rain depth available from farm rain gage.

† Irrigation rate was 64 mm/h, system moved at 29 m/h, 9 m wetted radius.

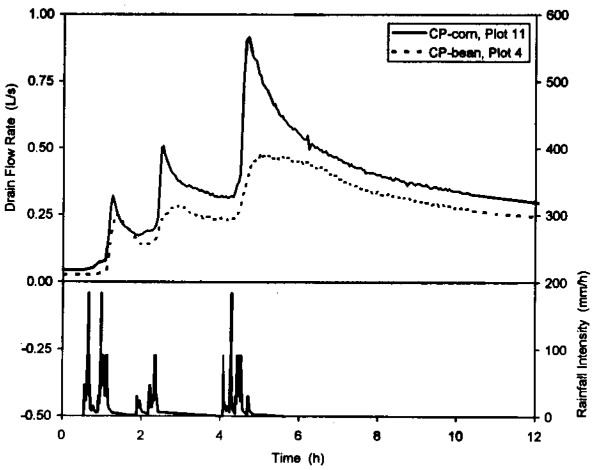

Figure 6–Subsurface drain flow hydrographs for plots 4 and 11 for event 5 (1993).

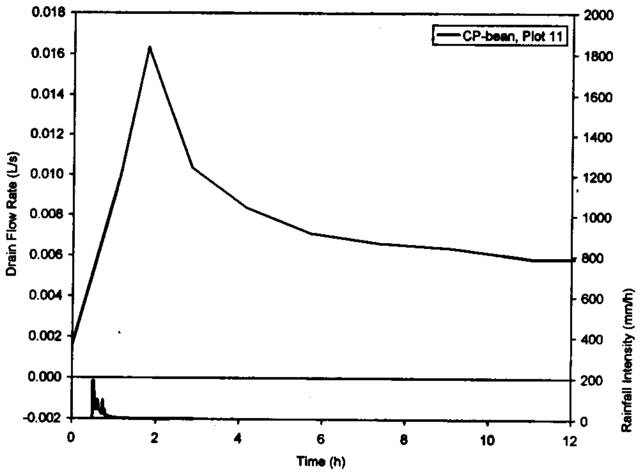

Figure 7–Subsurface drain flow hydrograph for Plot 11 for event 1 (1994; No flow from Plot 4).

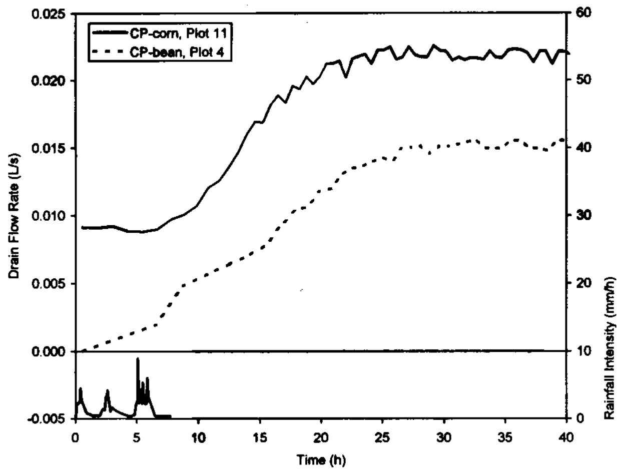

Figure 8–Subsurface drain flow hydrographs for Plots 4 and 11 for event 2 (1995).

varied from 0 to 3 h and times-to-peak varied from 10 min to 10 h. Peak drain flow rates sometimes exceeded 1 L/s. Drainage volume ranged from 0.05 to 2.7 cm/event. Using the hydrograph separation technique, preferential flow was found to influence less than 10% of the total volume drained for 1993 drainage events (48 values). Only two preferential flow values exceeded 10% of the total flow for both 1994 (91 values) and 1995 (79 values) drainage events. For multi-response events, preferential flow usually influenced only the initial response because drainage rate changes were relatively small for the following sub-events (i.e., events 2b, 3b, etc.). This indicates that little preferential flow occurred when the soil was wet from a recent rain. Furthermore, preferential flow was identified on only two plots for drainage events 1 and 2 in 1995, which were preceded by more than 10 mm of rain within the previous 24 h and had maximum rainfall intensities of less than 10 mm/h.

Drainage parameter graphs showed little correlation between any variables. Drainage volume tended to increase as peak drain flow rate increased. The highest peak flow rates and percent preferential flows occurred when times-to-peak was less than 100 min. However, peak rate and preferential flow were also frequently almost zero when time-to-peak was less 100 min. Percent preferential flow also did not correlate with rainfall intensity. The highest average percent preferential flow did not occur when rainfall intensity was highest (tables 1 and 2). The highest average preferential flow for NT-corn and NT-bean during the study occurred during event 5 (1994). CC and CP-bean had the highest average preferential flow of the during event 2 (1993) when maximum rainfall intensity was less than 20 mm/h. The irrigation event in 1994 resulted in the highest average preferential flow for CP-corn.

For 1993, CC and CP-bean had significantly greater drainage volumes and higher peak drain flow rates than CP-corn, NT-corn, and NT-bean (table 3). Larger drainage volumes and higher peak rates from these chisel plow plots conflicts with the conventional belief that more water flows through no-till soils due to preferential flow. However, 1993 was a transition year and the extremely wet conditions may have limited macropore development, especially cracks and fractures, which may be the reasons why preferential flow was not significantly different between the no-till and chisel plow tillage systems. Other significant differences between farming systems occurring in 1993 were faster response times from CP-bean than CP-corn and higher peak flow rates from NT-bean than NT-corn.

NT-bean had significantly slower response times and smaller peak drain flow rates than NT-corn for 1994 drainage events (table 3). CC and CP-bean also had

Table 2. Average percent preferential flow by drainage event

Events	Continuous Corn	Rotation Corn		Rotation Soybean	
	CP	CP	NT	CP	NT
1993 1	1.5	1.4	2.7	2.8	1.8
2	6.0	0.9	1.8	9.2	6.0
3	1.7	3.3	1.8	3.0	1.3
4	1.6	1.1	1.9	4.1	2.0
5	0.2	2.8	2.9	2.5	2.9
1994 1	0.0	0.7	2.0	3.5	8.6
2	2.2	1.2	4.4	3.0	0.8
3	1.8	2.9	1.6	0.9	0.4
4	1.8	2.2	0.5	2.4	0.5
5	3.6	1.7	6.1	0.0	9.1
6	2.1	3.4	2.1	0.0	2.3
1995* 3	0.5	0.0	2.4	1.2	2.0
4	1.2	1.0	0.3	na†	2.8
5	0.0	0.0	0.1	0.2	0.1
6	1.4	0.2	1.3	3.4	7.2
7	0.3	0.2	0.3	0.3	0.7

* Only two plots had preferential flow during events 1 and 2 of 1995.
† No data available from chisel plow soybean for event 4 (1995).

Table 3. Crop and tillage system comparisons from Wilcoxon signed-rank test for paired differences

1993	
Response time	CP-corn > CP-bean
Time-to-peak	nsd*
Drainage volume	CP-bean, CC > CP-corn, NT-corn, NT-bean
Peak drain flow rate	CP-bean, CC > CP-corn, NT-corn, NT-bean NT-bean > NT-corn
Percent pref. flow	nsd*
1994	
Response time	NT-bean > NT-corn
Time-to-peak	CP-corn > CC, CP-bean, NT-corn
Drainage volume	nsd*
Peak drain flow rate	NT-corn > CC, CP-bean, NT-bean
Percent pref. flow	nsd*
1995	
Response time	CC, CP-bean > NT-corn
Time-to-peak	CP-corn > CC, NT-bean, NT-corn CP-bean >NT-corn
Drainage volume	NT-bean, NT-corn, CP-bean > CC > CP-corn
Peak drain flow rate	NT-bean, NT-corn, CP-bean > CC > CP-corn NT-bean > CP-bean
Percent pref. flow	NT-bean > CC > CP-corn CP-bean > CP-corn
3-years Combined	
Response time	CC > NT-corn
Time-to-peak	CP-corn > CC, NT-corn, CP-bean
Drainage volume	NT-bean, NT-corn, CP-bean, CC > CP-corn
Peak drain flow rate	CP-bean, NT-bean, CC > CP-corn CP-bean > CC
Percent pref. flow	NT-bean > CC

* No significant differences at p = 0.05.

significantly faster times-to-peak than CP-corn and lower peak drain flow rates than NT-corn. Drainage volume and preferential flow were not significantly different between any of the five farming systems in 1994.

Drainage event parameters began to indicate more preferential flow from NT-bean and NT-corn by 1995. NT-bean was the only system to have any preferential flow during events 1 and 2 of 1995. NT-corn had significantly faster response times than CC and CP-bean and faster times-to-peak than CP-corn and CP-bean. NT-corn and NT-bean also had greater drainage volumes and peak drain flow rates than CC and CP-corn. NT-bean also had significantly faster times-to-peak than CP-corn, greater peak drain flow rates than CP-bean, and greater percent preferential flow than CC and CP-corn.

Statistical results of combined data for all three years were somewhat similar to the 1995 results (table 3). CC had significantly longer response times than NT-corn and less preferential flow than NT-bean. CP-corn had smaller drainage volumes than all other systems. CP-bean and CC also had significantly faster times-to-peak and higher peak drainage rates than CP-corn. No significant differences occurred for any drainage event parameter when data were combined by tillage (NT vs. CP) or crop (corn vs. soybean).

Annual averages of drainage event data show a few trends (table 4), however, these must be viewed with caution because the data were highly variable. (Coefficients of variation were usually between 0.6 and 1.1.) CP-corn always had the slowest annual average time-to-peak. NT-corn had the fastest or second fastest time-to-peak. NT-bean tended to have the highest percent preferential flow while CC tended to have the lowest. Drainage volume, and to a lesser extent peak drainage rate, seemed to be influenced more by the experimental plot than crop. CP plots planted to soybean in 1993 and 1995 and planted to corn in 1994 had the highest average drainage volumes. However, CP plots planted to soybean in 1994 and corn in 1993 and 1995 had the lowest average drainage volumes. Furthermore, average drainage volumes and peak drainage rates from soybean plots were greater in 1993 and 1995 and less in 1994 than rotation corn plots for both NT and CP tillage systems.

Table 4. Annual average drainage parameter values

	Continuous Corn	Rotation Corn		Rotation Soybean	
	CP	CP	NT	CP	NT
Response Time (min)					
1993	64	65	61	59	58
1994	43	23	16	20	25
1995	137	191	87	141	158
Time-to-Peak (min)					
1993	67	110	67	68	93
1994	39	62	23	32	54
1995	230	479	239	280	261
Drainage Volume (mm)					
1993	8.6	6.2	7.1	8.8	7.2
1994	2.7	3.5	3.2	2.3	2.5
1995	5.6	3.0	7.5	8.9	8.3
Peak Drain Flow Rate (L/s)					
1993	0.42	0.34	0.30	0.49	0.39
1994	0.08	0.09	0.18	0.08	0.07
1995	0.24	0.07	0.34	0.36	0.40
Preferential. Flow (%)					
1993	1.9	1.8	2.2	3.5	2.7
1994	1.9	2.0	3.3	2.2	3.6
1995	0.5	0.2	0.6	0.8	1.9

CONCLUSIONS

Data from the subsurface drain monitoring system showed that subsurface drains must be monitored at short time intervals to detect rapidly occurring changes in subsurface drain flow rates. Drainage rates occasionally increased 10-fold within 30 min. These rapid changes emphasize the importance of collecting continuous water samples for water quality studies. Discrete samples collected daily or weekly do not adequately sample drain effluent at varying flow rates.

The data acquisition system worked well for measuring subsurface drain flow rate response to rain events, except larger sump pumps would have reduced the chances of drain flow rate exceeding the pumping rate. A hydrograph separation technique, used to estimate the preferential flow influence on subsurface drainage, indicated that preferential flow was usually less than 10% of the total event drainage. Significant differences in preferential flow from crop and tillage systems only occurred during third year of the study (1995), when preferential flow from NT-bean was greater than CC which was greater than CP-corn. CP-bean also had greater preferential flow than CP-corn in 1995.

Annual average data indicated that drainage volume and peak drainage rate may have been influenced more by the experimental plot than by the crop. No trends or patterns in statistical differences between crop and tillage systems were evident during this study. Inconsistent significant differences in these drainage event parameters may relate to lack of differences between these tillage systems. The only difference in tillage between no-till and chisel plow was CP-corn, CP-bean, and CC plots were chisel plowed in the fall. Soybean plots were not cultivated during the study and all corn plots were cultivated in 1994 and 1995. Furthermore, tillage only influences the top 10 to 20 cm of soil, which is a small portion of the soil that water must flow through before reaching a subsurface drain. Previous research at this site indicated that site variability may have a greater effect on infiltration than tillage (Logsdon et al., 1993). High variability of data from this study demonstrates the complexity of characterizing water flow through soil to subsurface drains.

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