WATER BALANCE INVESTIGATION OF DRAINAGE WATER MANAGEMENT IN NON-WEIGHING LYSIMETERS

K. D. Riley, M. J. Helmers, P. A. Lawlor, R. Singh

ABSTRACT. *Artificial subsurface drainage systems are often used throughout the upper Midwest to remove excess precipitation and improve crop production. However, these drainage systems export nitrate-nitrogen (NO_3-N) to downstream water resources. Management practices are needed to reduce this export of NO_3-N with subsurface drainage water. One such practice being considered is the use of drainage water management where subsurface water is held in the soil profile during portions of the year. Previous research has shown that drainage water management has potential to reduce subsurface drainage volume but there is still a need to understand the performance of the practice and the pathways of water flow under varying conditions. The objectives of this study, therefore, were to quantify the pathways of water movement for conventional or free drainage (FD) and drainage water management (DWM) during the growing season. In this study, six non-weighing lysimeters (0.92 × 2.30 m) with a depth of 120 cm were monitored over a 3-yr period under natural and simulated rainfall conditions. The objectives were performed to measure the effects of drainage water management (DWM) on surface runoff, subsurface drainage, and crop yield. The in-season data from natural rainfall conditions showed that DWM reduced subsurface drainage by approximately 14%. The simulated rainfall data showed that DWM increased surface runoff by 54% when the water table was established at 90 cm below the soil surface, and by 87% when the water table was established at 60 cm below the soil surface. Overall DWM was found to have the potential to reduce subsurface drainage but there is the potential that at least a portion of this reduction may be reflected in an increase in surface runoff.*

Keywords. *Subsurface drainage, Surface runoff, Drainage water management.*

S60ubsurface drainage has been a successful practice in removing excess precipitation and improving the crop production in poorly drained soils across upper Midwestern United States. However, the nitrate-nitrogen (NO_3-N) export with subsurface drainage water from the upper Midwestern agricultural fields has been implicated as a major contributor to the hypoxic zone in the Gulf of Mexico at the mouth of the Mississippi River (Turner and Rabalais, 1994; Sen Gupta et al., 1996; Rabalais et al., 1999). Researchers have been studying various drainage management practices to reduce NO_3-N export from agricultural fields. One practice under consideration is drainage water management. It has shown positive impacts on reducing the volume of subsurface drainage and on reducing the export of NO_3-N. Drainage water management is a method of subsurface drainage management, where water is held in the soil profile during portions of the growing season rather than being released unhindered.

Subsurface drainage volume reduction by drainage water management (DWM), compared to conventional or free drainage (FD), has been reported to be in the range of 10% to 40% (Gilliam and Skaggs, 1986; Fouss et al., 1987; Evans et al, 1995; Skaggs et al., 1995a, 1995b; Drury et al., 1997; Amatya et al., 1998; Tan et al., 1998; Drury et al., 2001), although a reduction as high as 65% has been reported (Lalonde et al., 1996). As a result of reduction in subsurface drainage volumes, a reduction in NO_3-N export is expected. Previous research has reported NO_3-N export reductions on the order of 20% to 40% when comparing DWM to FD (Skaggs and Gilliam, 1981; Deal et al., 1986; Gilliam and Skaggs, 1986; Evans et al., 1995; Skaggs et al., 1995a, 1995b; Drury et al., 1996; Brevé et al. 1997, 1998; Tan et al., 1998; Elmi et al., 2000; Drury et al. 2001; Ng et al., 2002).

Despite these positive results, there is still a need to further understand DWM, in particular, investigating the pathways of water movement in a DWM system. One concern is that higher surface runoff may occur when DWM is implemented because of the wetter soil profile associated with the higher water table under a DWM system (Singh et al., 2007). Logically, when surface runoff increases there is an increased risk of erosion and as a result an increase in phosphorus and pesticide transport. Previous studies of DWM, including a surface runoff component through monitoring or modeling, have reported surface runoff increases on the order of 10% to 60% (Deal et al., 1986; Evans et al., 1995; Skaggs et al., 1995b; Brevé et al., 1997; Drury et al., 2001; Grigg et al., 2004; Singh et al., 2007). Furthermore, Skaggs et al. (1995b) reported, from DRAINMOD modeling simulations, increased surface runoff of 68% with DWM implementation and 164% when DWM was intensified by bringing the water table up to 25 cm below the soil surface from 15 September to 15 March instead of 40 cm below the soil surface.

Another area of question, relative to DWM, is the impact on crop yields, especially since there is a cost associated with

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DWM implementation and management. Differences in crop yield under DWM versus conventional drainage have been inconsistent. For example, studies by Brevé et al. (1997 and 1998) reported little increase or decrease in crop yields between the drainage treatments. Studies by Fisher et al. (1999) and Hunt et al. (1993) reported a 10% to 20% increase in corn yield under the DWM system. This suggests that water retention in the soil profile by DWM improved the crop yields. However, Grigg et al. (2004) reported about a 3% decrease in corn yield under DWM system. This suggests that a higher water table could have negative impacts on root proliferation early in the season, and thereby decrease crop yields.

While previous research has shown that DWM has potential to reduce subsurface drainage volume, there is still a need to understand the performance of the practice under varying conditions. Some information on surface runoff exists, but there is a strong need to further document potential pathways of water movement under DWM conditions. The impact of such practices also depends on the local rainfall/drainage patterns in the region. The objectives of this study, therefore, were to quantify pathways of water movement for conventional or free drainage (FD) and drainage water management (DWM) during the growing season under natural and simulated rainfall conditions in Iowa using small-scale non-weighing lysimeters. In the Midwest, much of subsurface drainage occurs during the months of April through June (Randall and Vetch, 2005) due to the melting of snow and ice after the winter period (November-February). Increased rainfall also occurs during spring and summer. Therefore, water flow was monitored from March through October.

MATERIALS AND METHODS

RESEARCH SITE

The research site was comprised of six non-weighing lysimeters that contain Clarion Loam (Fine-loamy, mixed, superactive, mesic, Typic Hapludolls) soil that has been under continuous corn cultivation (a simulated 24,000 plants per acre) since their installation in 1993. The lysimeters are 0.92 m wide, 2.30 m long, and 1.20 m deep (fig. 1). They are fitted with a 380-mm diameter PVC sump, which was connected with a 100-mm diameter perforated plastic drain at the bottom. The lysimeters are sealed on the bottom and sides so that the pathways of water movement out of the lysimeters are restricted to subsurface drainage, surface runoff, or evapotranspiration. To facilitate lysimeter installation, soil was removed in 15-cm increments to excavate for placement of lysimeter sides and bottom. During this process, the soil from each 15-cm increment was separated and then repacked into the lysimeters at the same depth from which it was excavated. To maintain a relatively consistent bulk density with the original soil conditions, each 15-cm increment of soil that was excavated was again repacked to a 15-cm increment within the lysimeter. This process was completed in 1993 and, as indicated previously, since this time the lysimeters have been under continuous corn cultivation. The site is located about 10 km west of Ames, Iowa. This research took place during the 2005, 2006, and 2007 growing seasons with corn planted in all years. Urea ammonium nitrate (UAN) was applied at 168 kg-N/ha in 2005 and at 224 kg-N/ha in 2006 and 2007. The rate was increased in 2006 to insure nitrogen was not a limiting factor for crop growth. UAN was applied as solution in the spring before all growing seasons and incorporated to a depth of 10 cm with a garden rotary tiller. Spring tillage was completed using a garden rotary tiller in the 2005 growing season and fall tillage was done in the fall of 2005 and 2006 again using a garden rotary tiller.

TREATMENTS

The six lysimeters that make up the research site were divided into two different treatments (FD and DWM) using a completely randomized design. Treatments were not re-randomized each year. All six lysimeters were monitored during the drainage seasons (April through October) of the years 2005, 2006, and 2007. The lysimeters under FD

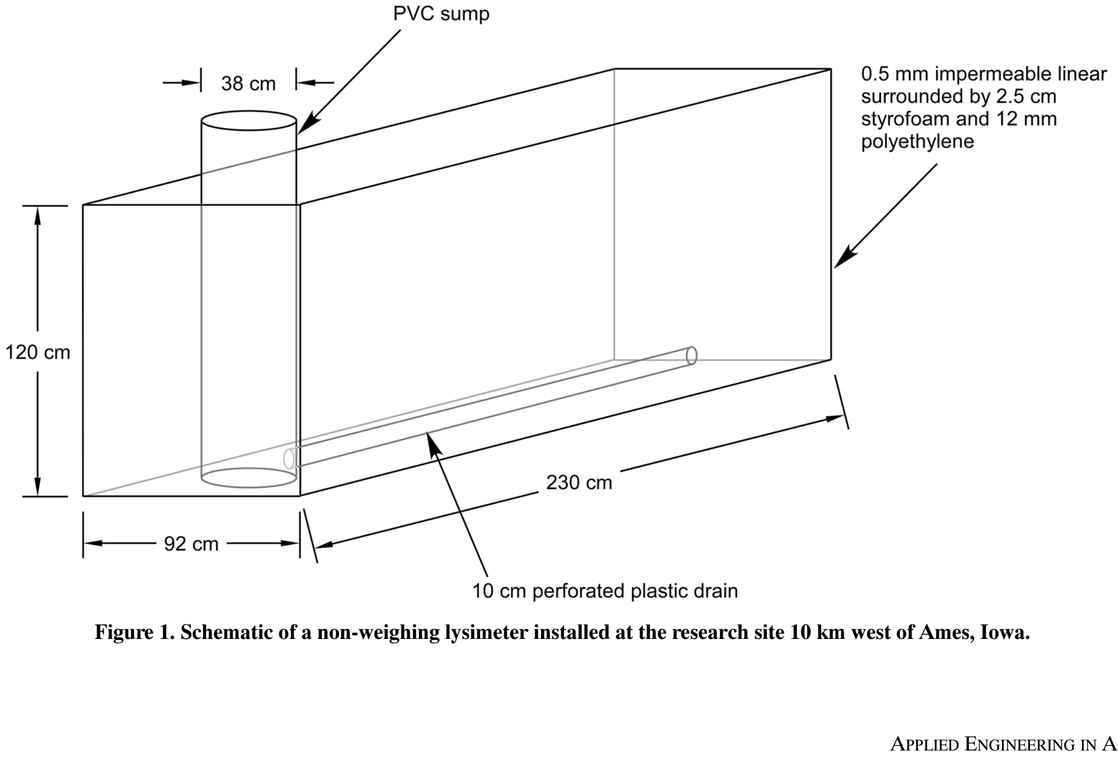

Figure 1. Schematic of a non-weighing lysimeter installed at the research site 10 km west of Ames, Iowa.

Table 1. Dates for drainage water management operation.

Year	Structures Open	Structures Closed
2005	4/15 - 6/13	6/13 - 9/20
	9/20 - 10/6	10/6 - 12/31
2006	3/30 - 6/1	6/1 - 9/27
	9/27 - 10/13	10/13 - 12/31
2007	4/1 - 5/25	5/25 - 9/20
	9/20 - 10/11	10/11 - 12/31

conditions drained as a simulated conventional tile drained system with the drain open during the entire year. The drain depth for the FD plots was 120 cm. The lysimeters under DWM conditions drained similar to FD during planting and harvesting and then during the growing season and during winter the water level was allowed to reach 60 cm below the soil surface before draining. However, the time period that the lysimeters were in FD or DWM depended on that particular growing season based on environmental conditions (table 1).

DATA COLLECTION

The lysimeters were monitored for subsurface drainage and surface runoff from natural rainfall during the years 2005, 2006, and 2007. Since it is expected there would be little subsurface drainage during the winter months due to freezing conditions and lack of moisture (Lawlor et al., 2008) combined with the concerns about the breakage of pumping equipment during the winter months, water flow was not measured during these periods. Weather information for this site was obtained from a National Oceanic and Atmospheric Administration weather station located 0.5 km northeast of the plots (COOP ID: 130200). Since all systems were in conventional drainage prior to the spring of 2005 and rainfall simulations where performed in the spring of 2006, the monitoring period under natural rainfall for all systems was from mid-April through late-October in each year. From this, the systems functioned in FD from mid-April through late-May or early-June, the drainage water management systems then had an outlet level of 60 cm below the ground surface from this time period until near harvest, followed by FD in all systems during the harvest period, and then finally the DWM again had outlet control after harvest through the end of the monitoring season (table 1). Prior to winterizing the lysimeters, the water was pumped completely out of the lysimeters to minimize breakage during the winter. So, the drainage volumes reported herein do not include any potential volume reductions as a result of drainage water management throughout the winter months since the initial condition for all lysimeters was the same at the start of the monitoring season. As such any volumetric reductions in subsurface drainage are the result of volume differences during the growing season. Due to conditions in Iowa it was expected that the primary period when subsurface drainage volumes would be affected by DWM or FD was during the growing season (Singh et al., 2007).

Subsurface drainage volumes were determined during monitoring periods and during the rainfall simulations (described later). The subsurface drainage data was collected on average every seven days during the monitoring period from April to October. A submersible sump pump in the PVC sump was used to pump water out and the volume was measured via a container that was calibrated in 2-L increments. For the DWM system the submersible pump was raised to within 60 cm of the ground surface. To collect surface runoff, a drain was cut in the side of the lysimeter to allow the runoff to drain into a catch container. When runoff occurred, the volume of water in the catch container was measured via the same calibrated bucket, except during the rainfall simulations. During rainfall simulations, time constraints lead to the use of a rotation of catch containers so that the incremental mass of the runoff could be determined separately using an on-site balance. Rotation of catch containers consisted of the use of two similar containers so that when one container was being weighed the other would be used for runoff collection. This procedure was used to ensure complete data collection during the rainfall simulation event. The volume was then calculated using the measured mass. Annual summaries of subsurface drainage do not include drainage that occurred during the rainfall simulation periods. Following rainfall simulations the lysimeters were allowed to drain under free drainage conditions before commencing the growing season monitoring.

In addition to monitoring surface runoff and subsurface drainage, corn grain yields were measured. For the yield data, the corn in all years was hand harvested, corn ears where shelled, and then the moisture was measured on corn grain via a handheld electronic moisture meter. The mass of the corn grain was measured using a common mass balance. Also, during the majority of the monitoring periods in 2006 and 2007 the depth of water in the PVC sump in the lysimeters was measured to assess the water table conditions during the summer period.

RAINFALL SIMULATIONS

In addition to monitoring the lysimeters during the growing seasons of 2005, 2006, and 2007, four rainfall simulations (A, B, C, and D) were conducted at the research site to document surface runoff and subsurface drainage under representative rainfall amounts (table 2). The rainfall simulations were conducted on each lysimeter individually and the simulator used was 2.5 m high and had an oscillating spray bar. Once activated, the spray bar provided a sweeping spray over the entire lysimeter every 5 s. To prevent unwanted water in or out of the lysimeters, each lysimeter was covered in between each simulation and pre-treatment. Residue cover during all simulations was perceived to be 10% to 20%, but was not formally measured.

Rainfall simulations A and B took place in the fall of 2005 with a pre-wetting treatment (25 mm/h^{-1}) applied by the simulator followed by a 1-h simulation rainfall event with an intensity of 45 mm/h^{-1}. This 1-h design storm has

Table 2. Summary of rainfall simulation scenarios.

Date	Simulation	Simulation Rate (mm/h)	Average Rainfall Measured (mm/h)	Pre-Treatment	Lysimeters Involved
Fall 2005	A	45	44	Pre-wet (100 mm)	All
Spring 2006	D	45	46	Saturation from bottom	All

approximately a 5-yr recurrence interval for the study area (CTRE, 2007). Rainfall simulations C and D took place in the spring of 2006 with field saturation pre-treatment before the simulations. Simulation C had a 1-h rainfall simulation with an intensity of 25 mm/h^{-1}. This design storm is estimated to have between a 6-month and 1-yr recurrence interval for the study area (CTRE, 2007). Simulation D had the same rainfall duration and intensity as simulations A and B. A more frequent design storm was conducted in simulation C to determine if it would have the same effects as in simulations A and B.

The pre-wetting treatment in the fall of 2005 consisted of a 25-mm/h^{-1} rainfall for 4 h for a total of 100 mm. The lysimeter was then pumped out until there was no water freely draining from the soil which took approximately 3 days and then the simulation was conducted. Simulation A consisted of a 45-mm/h rainfall for a period of 1 h on each the six lysimeters. During the pre-wetting, and after simulation A, measurements showed the DWM lysimeters were not at the DWM level of 60 cm below the soil surface. Therefore, the DWM lysimeters were pre-wet again at the 25-mm/h^{-1} rate until the DWM level was reached in all three DWM lysimeters, approximately 50 cm below the soil surface. After the DWM level was reached simulation B was conducted using only the three DWM lysimeters with a rainfall rate of 45 mm/h^{-1}.

The field saturation pre-treatment for simulations C and D consisted of pumping water from a nearby well into the sump of the lysimeter to completely saturate the lysimeter from the bottom to the top. This approach was used to reduce the air trapped in the soil and allow the lysimeter to reach as close to saturation as possible prior to draining. After saturating, the FD lysimeters were pumped out until there was no water freely draining. For the DWM lysimeters, the water was pumped out to 60 cm below the soil surface. Simulation C, which consisted of a 25 mm/h^{-1} rate for 1 h, was first conducted on the DWM lysimeters. Since there was no surface runoff from these simulations, Simulation C was not started and performed on the FD lysimeters since one of the objectives of the rainfall simulations was to determine the impacts of DWM on surface runoff. Rather, simulation D (45 mm/h^{-1} rainfall for 1 h) was conducted on all six lysimeters. Since rainfall simulation C had been conducted on the DWM lysimeters, the DWM lysimeters were saturated from the bottom again prior to conducting simulation D. Since simulations B and C were not conducted on both the FD and DWM lysimeters, only the results for simulations A and D are presented within.

STATISTICAL ANALYSIS

The statistical analyses were conducted using Statistical Analysis System software (SAS, 2003). The general linear model (GLM) procedure was used to determine the statistical significance of treatment effects on simulation surface runoff, in-season subsurface drainage, and corn yield data. The mean values for the subsurface drainage and corn yield were separated using a least significance test at p = 0.05($\text{LSD}_{0.05}$) and p = 0.10($\text{LSD}_{0.10}$).

RESULTS AND DISCUSSION

NATURAL RAINFALL CONDITIONS

All years had near normal or slightly above normal precipitation (fig. 2). The greatest precipitation was measured in 2007, and 2007 had the greatest subsurface drainage volume of the three years (table 3). In all years the subsurface drainage from the DWM treatment was less than the subsurface drainage from the FD treatment. However, there was only a significant difference in 2006. The 3-yr average was also significantly different with DWM having lower subsurface drainage volumes than the FD treatment. Based on the 3-yr average drainage volumes, there was approximately 14% reduction in the subsurface drainage volume with DWM system. The drainage results support previous research with DWM having less subsurface drainage and are similar to the 15% average reduction with DWM that was modeled for Iowa conditions by Singh et al. (2007). During all years, the majority of the monitored subsurface drainage occurred during the spring free drainage period when both DWM and FD are in the conventional or free drainage mode (fig. 3). This was consistent with monitoring data from Lawlor et al. (2008) where nearly 43% of the annual drainage occurred in April and May during a 16-yr period in north-central Iowa.

The water level dropped in the PVC sump during the 2006-2007 growing seasons until precipitation increased soil moisture and the water level in the sump increased in late summer (figs. 4 and 5). It is expected that the water loss in the

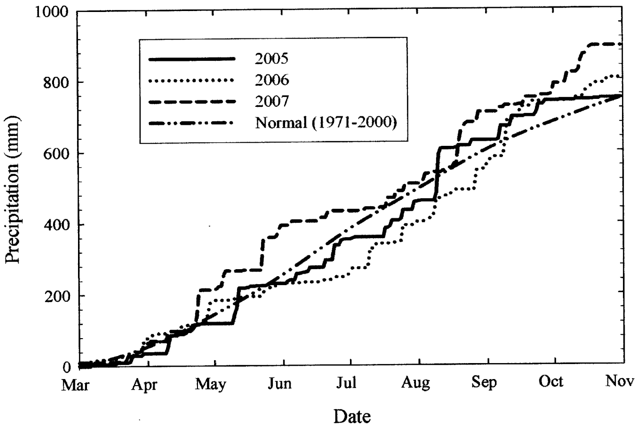

Figure 2. Precipitation for the 2005, 2006, and 2007 drainage seasons.

Table 3. In-season subsurface drainage (mm) under different drainage treatments.

Treatment	Average Subsurface Drainage during Monitoring Period (mm) 2005	2006	2007	Average
Drainage water management	267	149	314	243
Free	286	223	333	281
$\text{LSD}_{0.05}$	NS[a]	60.3	NS	30.3
$\text{LSD}_{0.10}$	NS	46.3	NS	24.9

[a] Not significant.

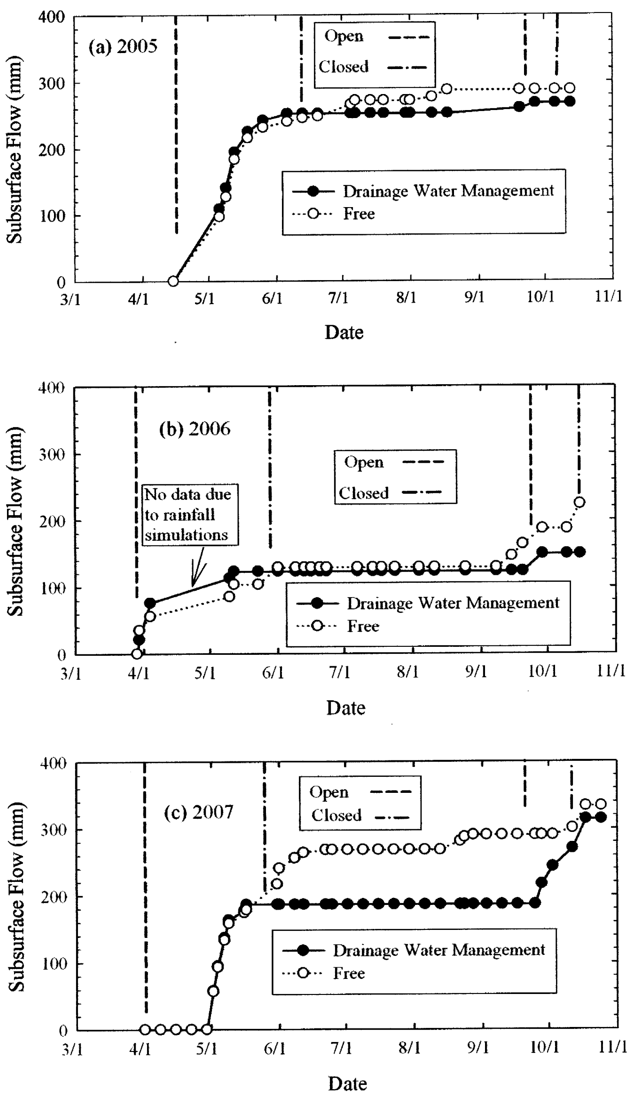

Figure 3. In-season subsurface drainage measurements in (a) 2005, (b) 2006, and (c) 2007.

summer months is due to evapotranspiration by the corn crop and from the soil surface. While the corn yield was greater in all years from the DWM treatment, there were no significant corn yield differences between the FD and DWM treatments (table 4).

The in-season monitoring period during 2005 and 2007 had negligible surface runoff associated with both FD and DWM treatments. In 2006, there was surface runoff for both treatments, but overall there was little runoff due to lower than average precipitation. The total surface runoff in 2006 was 31 mm and 33 mm for the DWM and FD treatments, respectively.

RAINFALL SIMULATIONS

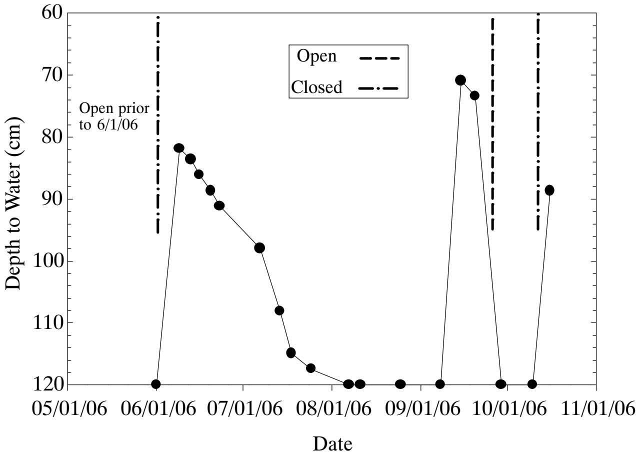

Figure 4. Depth to water in the sump during the drainage water management period in the 2006 growing season.

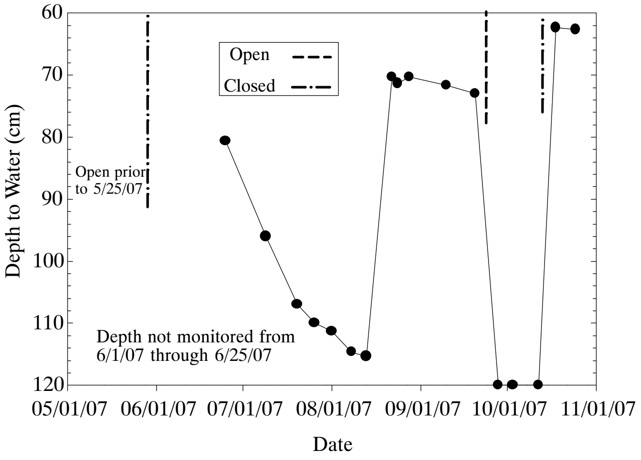

Figure 5. Depth to water in the sump during the drainage water management period in the 2007 growing season.

From the rainfall simulation data for simulation A (fig. 6, table 5) the average surface runoff for DWM and FD treatments was 20% and 13% of the total rainfall, respectively. This showed a 54% increase in surface runoff when DWM was compared to FD, but due to variability in runoff volumes this was not significantly different. Despite this, the results indicate the potential for increased surface runoff under DWM treatments.

From simulation D (fig. 7, table 5) the average surface runoff for DWM and FD treatments was 43% and 23% of the total rainfall, respectively. This showed an 87% increase in surface runoff when DWM was compared to FD, but again was not significantly different. Since Simulation C, which produced no surface runoff, was only conducted on the DWM lysimeters there is the possibility that there may have been some surface sealing of the DWM lysimeters compared to the FD lysimeters prior to Simulation D and that some of the surface runoff increases could be attributed to surface sealing. However, since Simulation C had the lowest rainfall intensity (25 mm/h^{-1}) there may be uncertainty about the

Table 4 Corn grain yield under different drainage treatments.

	Corn Grain Yield (kg ha^{-1})[a]			
Treatment	2005	2006	2007	Average
Drainage water management	10,700	11,700	7,390	9,930
Free	8,920	10,700	6,850	8,820
LSD$_{0.05}$	NS[b]	NS	NS	NS
LSD$_{0.10}$	NS	NS	NS	NS

[a] Corn grain yield corrected to a moisture content of 15.5%.
[b] Not significant.

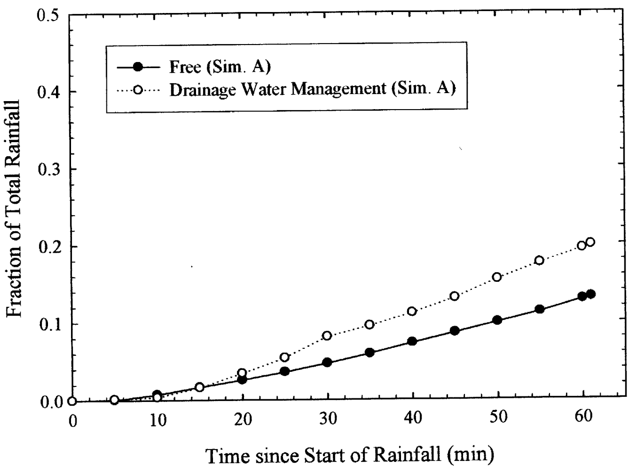

Figure 6. Surface runoff measurements for rainfall simulation A.

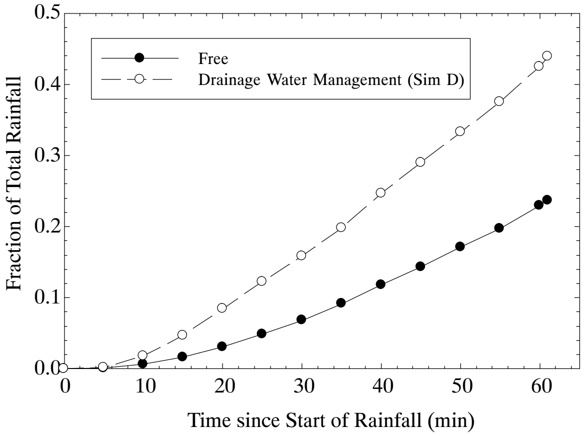

Figure 7. Surface runoff measurements for rainfall simulation D.

Table 5. Surface runoff expressed as percent total rainfall under different rainfall simulation scenarios.

Treatment Comparisons[a]	Sim		Reps (runoff as % of total rainfall)		Average (runoff as % of total rainfall)
DWM	A	26	20	13	20
FD	A	22	11	5	13
DWM	D	52	27	49	43
FD	D	30	38	2	23

[a] DWM = Drainage water management.
FD = Free drainage.

extent of surface sealing or surface compaction. Although statistical significant differences were not found in direct comparisons of the simulation results, the results indicate that the DWM treatments had the potential to increase surface runoff due to a wetter soil profile.

During simulation A, the water table in the DWM lysimeters was approximately 90 cm below the soil surface, which is 30 cm lower than the intended 60 cm below the soil surface. However, a water table of 60 cm below the soil surface was then used in simulation D. Taking these conditions into consideration, the results in simulation A and D support the model findings in Skaggs et al. (1995b) that surface runoff increases as DWM was intensified by raising the DWM level from 90 cm below the soil surface in simulation A up to 60 cm below the soil surface in simulation D.

Simulation C, which consisted of a 25 mm/h^{-1} rate for 1 h, was conducted on the DWM lysimeters but since there was no surface runoff from these simulations, Simulation C was not conducted on the FD lysimeters. The surface runoff of DWM and FD treatments from simulation D (fig. 7) was greater than that of simulation A (fig. 6). Due to the saturation pre-treatment in simulation D, more air was replaced by water in the soil pores when compared to the pre-wetting of simulation A. This left the soil in a state where it had a lower soil water storage capacity due to the higher amount of moisture in the soil. This led to the surface runoff increasing for the FD treatments in simulation D by 77% when compared to the FD treatments in simulation A. Similarly, the surface runoff for DWM treatments in simulation D was increased by 115% when compared to the DWM treatment in simulation A. Overall, the results indicate that as soil water storage capacity is reduced with the use of DWM there is the potential for greater surface runoff from some rainfall events.

The subsurface drainage was also measured during the rainfall simulation scenarios (figs. 8 and 9). On average, the DWM treatments had lower subsurface drainage than FD treatments. The water balance summaries for runoff and drainage from the simulations are shown in table 6. In simulation A, the DWM treatments had only 20% of total rainfall as surface runoff released from the system. The other 80% was held in the soil due to the 90-cm water table instead of the 60-cm water table during the simulation. The FD treatments released 79% of the total rainfall when both the surface runoff and the subsurface drainage were considered from simulation A. Since 100% of the total rainfall was not accounted for by surface runoff and subsurface drainage in simulation A, it was determined that there was still water storage capacity in the lysimeters prior to simulation A being conducted.

A saturation pre-treatment was used for Simulation D to remove entrapped air and thereby minimize the water storage capacity in each lysimeter. It was confirmed with simulation D that there was minimal water storage capacity since the surface runoff and subsurface drainage accounted for 100% of the total rainfall in the FD treatments and 97% in the DWM treatments in simulation D. Additionally, to supplement the water balance investigation through the rainfall simulations, the water that was pumped out after the saturation pre-treatment was measured, giving drained porosity measurements. These measurements concluded that the DWM treatments had an average of 31-mm less drained porosity than FD treatments (fig. 10). The difference was due to the fact that a water table, established at 60 cm below the soil surface, was left in the DWM treatments.

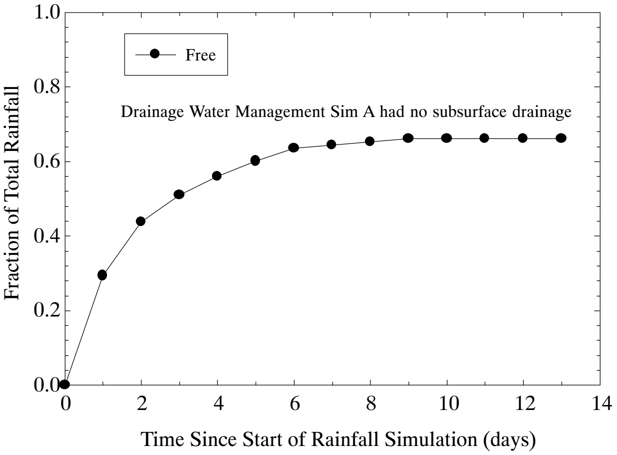

Figure 8. Subsurface drainage measurements for rainfall simulation A.

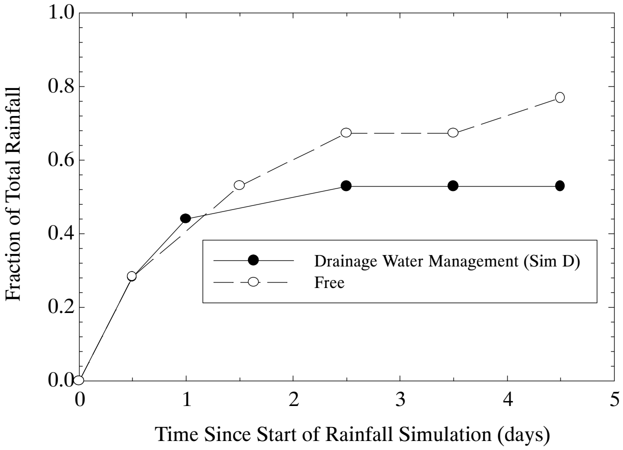

Figure 9. Subsurface drainage measurements for rainfall simulation D.

Table 6. Rainfall simulation water balance summary.

	Drainage Water Management			Free Drainage		
Simulation	Runoff (% total rainfall)	Drainage (% total rainfall)	Overall (% total rainfall)	Runoff (% total rainfall)	Drainage (% total rainfall)	Overall (% total rainfall)
A	20	0	20	13	66	79
D	43	54	97	23	77	100

CONCLUSIONS

The objectives of this study were to quantify the pathways of water movement for conventional or free drainage (FD) and drainage water management (DWM) during the growing season under natural and simulated rainfall conditions in Iowa using small-scale non-weighing lysimeters. In this study, the subsurface drainage was reduced by 14% when employing DWM treatments as compared to FD treatments over the 3-yr (2005-07) study period. These results are similar to the long-term modeled results for north-central Iowa (Singh et al., 2007). Corn yields were not significantly different between the DWM and FD treatments. The depth to water in the DWM treatments increased throughout the monitoring periods in 2006 and 2007 indicating that evapotranspiration occurred since there was no lateral or deep seepage from the lysimeters. Further studies are needed to document whether evapotranspiration increases with DWM.

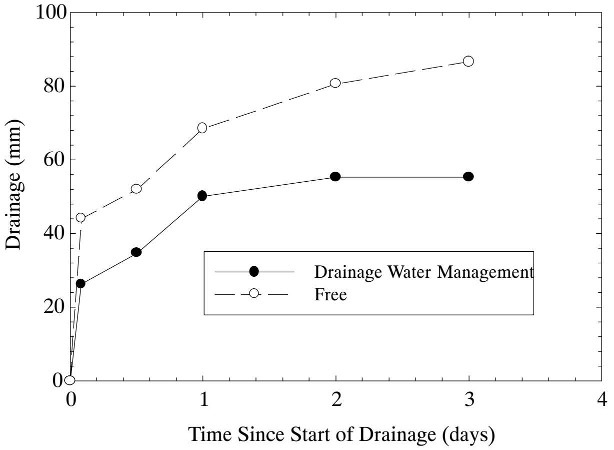

Figure 10. Drained porosity summary by different drainage treatments after rainfall simulation D.

The rainfall simulations that were conducted in the fall of 2005 and the spring of 2006 also support previous studies that indicate a potential for increased surface runoff with DWM system (Deal et al., 1986; Evans et al., 1995; Skaggs et al., 1995b; Brevé et al., 1997; Drury et al., 2001; Grigg et al., 2004; Singh et al., 2007). In all simulation scenarios where surface runoff occurred, surface runoff was greater in the DWM treatments when compared to the FD treatments for the 1-h duration design storm (45 mm/h^{-1}) with an estimated 5-yr recurrence interval.

While DWM significantly reduced subsurface drainage, there is the potential that this reduction may increase the volume of surface runoff. With the increased surface runoff there is an increased risk of soil erosion, and phosphorus and pesticide transport. The findings of this study highlight the need for field-scale studies that evaluate the overall water balance of drainage water management, in particular surface runoff, and if indeed surface runoff increases are documented on field-scale implementations of DWM remediation strategies should be developed to minimize any negative downstream impacts.

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