SUBSURFACE DRAINAGE AND LIQUID MANURE

By James J. Hoorman and Martin J. Shipitalo

Although land application of liquid animal wastes is a widely used BMP, in fields with subsurface drainage it can result in rapid movement to drains and offsite. In the four-year period, 2000 to 2003, ninety-eight incidents where agricultural wastes in drainage waters contaminated streams were recorded by authorities in Ohio. We investigated these reports to determine the factors that contributed to these incidents and to determine possible management options for reducing their occurrence. Violations occurred most frequently with liquid swine or dairy wastes and with all methods of application-irrigation, surface spreading, and subsurface injection. In most instances multiple factors contributed to each incident. The factor most commonly cited (41 cases) was application to saturated soils or heavy rainfall after application. Thus, avoiding these conditions should reduce the number and severity of incidents. While disruption of soil macropores with tillage may reduce movement of wastes to drains, 17 percent of the incidents occurred on soils that were tilled or wastes were incorporated. Drain line plugs failed 50 percent of the time they were used.

Table 1. Results of water quality tests downstream, at drainage outlet, and upstream from animal waste spills.

Water Test	Drainage Outlet	Downstream	Upstream	Ohio standards	Number of Observations
mg/L					
BOD_5	627.3	448.3	3.7	<15	18
Ammonia N	50.7	44.7	0.9	<13*	31
Nitrate + nitrate N	8.9	15.3	5.4	<10	13
TKN	109.7	78.0	2.7	Na	13
Total phosphorus	42.5	34.1	10.5	0.08 to 0.30	22
* Depends on pH and temperature					

Subsurface drainage improves crop growth and soil productivity, but can have detrimental environmental effects by increasing the movement of agrichemicals to surface water supplies (Kladivko et al., 2001). Frequently, this increased movement is attributed to preferential flow in soil macropores. Factors such as high intensity rainfall, dry soil, and conservation tillage, because it can contribute to the formation and preservation of soil macropores, increase the potential for preferential flow and enhanced chemical transport to occur (Shipitalo et al., 2000).

Liquid animal wastes are a valuable source of nutrients and organic matter for crop production and can be applied by a variety of methods including spray irrigation, surface spreading, and subsurface injection. Because of their low solids and nutrient content, liquid animal wastes are usually applied at relatively high volumes, but it is generally recommended that they not be applied at rates that would exceed the amount needed to bring the soil to field water holding capacity (Johnson and Eckert, 1995). Nevertheless, even when similar guidelines are followed, contamination of drain line effluent has been reported in soils with subsurface drainage due to macropore flow (Geohring et al., 2001).

The fact that liquid animal wastes can be safely land-applied in some instances, but can cause contamination of subsurface drainage water under different circumstances suggests that soil properties such as texture, initial water content, and tillage history as well as the amount of wastes applied, application method, water content of wastes, and the amount of rainfall after application may all play a role in determining the fate of the applied material.

In Ohio, the state Environmental Protection Agency (OEPA) has imposed substantial fines on producers that contaminate waters of the state when land applying liquid animal wastes. For example, in July 2004 a dairy farm received a $15,000 civil penalty for mishandling liquid wastes (OEPA, 2004). Various agencies keep records of causes and consequences of these types of violations. Therefore, our objective was to compile and examine liquid animal waste spill records for Ohio to determine the extent of the problem and as an aid to help determine conditions that promote contamination. We use this information to suggest methods to reduce the risk of liquid wastes reaching surface waters.

Gathering information

In Ohio, three agencies compile reports on liquid animal waste violations. The Ohio Department of Natural Resources (ODNR) - Division of Wildlife gets most of the calls to investigate reports of wastes in streams, dead fish, and stream littering. In some instances, information is collected by local Soil and Water Conservation Districts, and the OEPA Division of Surface Water collects detailed information on large spills and if legal action is anticipated. Reports from all three agencies were assembled resulting in a database of 98 violations from 1 January 2000 to 31 December 2003 where agricultural wastes entered subsurface drains and contaminated surface waters.

Violations

Fish kills. The death of fish and other aquatic wildlife are attributable to variety of natural and anthropogenic causes. An investigative study by the Dayton Daily News indicated that the number of fish kill incidents from all sources has decreased by 37 percent during the 30-year period from 1973 to 2002. However, the number of incidents attributable to agriculture, has increased by 72 percent in the same time period.

Of the fish kills attributed to agriculture, most are related to livestock production and land application of manure. The value of these fish, assigned by the incident investigators using standardized procedures, ranged from $15 to $65,300 (Figure 1).

Location of incidents. The 98 incidents where manure was found in subsurface drains occurred throughout Ohio (Figure 2). Most of these violations (58) occurred in the relatively flat northwestern part of the state where the soils are poorly drained and subsurface drainage is often required for crop production. The fewest incidents (4) occurred in the hilly southeastern region where systematic subsurface drainage systems are not commonly installed. Of the remaining incidents, 23 occurred in the southwest region and 13 in the northeast. We found some counties and regions were more diligent about reporting manure violations than others.

Characteristics of the livestock operations. Most of the 98 violations occurred on mid-sized swine farms (average of 2,355 head/operation) or large dairy farms (average 556 head/operation) with at least one million gallons (3.8 million liters) of liquid manure storage capacity (Figure 3). This is not surprising as typically these are the type of operations in Ohio that have liquid waste handling systems. Of the 39 operations that had a manure management plan, 28 operations (72 percent) were not following their plans when the violation occurred. The topography was mainly flat (< 6 percent slope) for 62 cases, rolling (> 6 percent slope) in 33 cases, and not reported in 13 cases.

Application timing, method, and rate. Violations occurred most frequently in the months of October-December (35 cases), when manure storage lagoons are typically emptied because the crops have been harvested making land available for application.

Out of the 98-recorded violations, 72 occurred when liquid manure was applied and 76 percent of these were surface applications. Irrigation was the most common method of surface application method, followed by tanker, and dragline. The reported average application rate was 0.59 inches, but this is probably an underestimate as measurements taken by the local SWCD or OEPA investigators indicated that application rates were, on average, two times higher than reported.

Given the uncertainty in application rate it is difficult to estimate the fraction of liquid manure that reached the subsurface drainage network. In ten instances where emergency remediation efforts were performed by the OEPA, however, they recovered 2,700 to more than 500,000 gallons (10,00 to 1,900,000 L) of liquid from the sites (average 86,450 gallons/327,200 L). They estimated that this amount was equivalent to an average of 16 percent (range 2 to 117 percent) of the amount applied. Since this estimate includes liquid wastes that were diluted by water in the ditches and streams it overestimates the actual amount lost and contributes to the high variability in the amount recovered.

Water quality. The data set on quality of the water upstream and downstream from the manure spills only covered a limited number of incidents and a limited set of chemical parameters, but suggested a significant impact on water quality (Table 1).

Reasons for incidents. Regardless of whether mismanagement occurred, preferential flow of the liquid wastes to subsurface drains via soil macropores was a major contributing factor to off-site movement of contaminants associated with liquid waste application. The reports indicated that soil cracks and earthworm burrows were cited as contributing factors in 21 percent of the incidents (Table 2). Tillage has been advocated as a method to disrupt macropore continuity and reduce losses of liquid wastes via subsurface drainage systems and a number of studies support this recommendation. In a laboratory study, Cook and Baker (2001)

Figure 1.
Officials quantifying the number of fish killed as a result of subsurface drainage discharge in Union County, Ohio. Courtesy of OEPA.

noted movement of water and bacteria associated with application of liquid swine wastes was reduced by tillage. Similarly, Jamieson et al. (2002) noted that tillage reduced bacterial transport. When they disked the soil prior to the application of liquid swine wastes Kay et al. (2004) noted that peak antibiotic concentration in drain flow was reduced by two orders of magnitude compared to application to standing crop stubble. Both Geohring et al. (2001) and Randall et al. (2000) noted that incorporation of liquid manure reduced phosphorus transport and Geohring et al. (2001) recommend plowing and avoiding application when rainfall is imminent as best management practices.

In 57 of the 98 incidents we investigated either the soil was not tilled or the liquid wastes were not incorporated, but in 14 cases tillage or incorporation were documented in the reports. Tilling the soil in a narrow band above the subsurface drains or avoiding waste application in this zone have been suggested as management options to reduce movement to tile lines (Shipitalo and Gibbs, 2000). Tillage will probably reduce movement of liquid wastes to subsurface drains, but it is not likely to eliminate it in all situations based on the incidents we investigated and the studies conducted by other researchers. Similarly, avoiding application in a relatively narrow zone above the sub-drains will probably not be entirely effective as recent studies have suggested that solutes and particulate matter can move laterally up to several yards (meters) in the near surface soil horizons before moving downward in preferential flow paths in tilled soils (Shipitalo et al., 2004) and in grassland (Stamm et al., 2002). In both these studies earthworm burrows were implicated as the dominant preferential flow paths leading from the near surface to the sub-drains, but in other soils cracks can assume this role (Kladivko et al., 2001; Simard et al., 2000).

Drain line plugs and catch basins as control measures. Once liquid wastes have entered a subsurface drainage system it is essential that it be prevented from being discharged into surface waters. One method of doing this is to install drain line plugs or stops at the outlets. These efforts failed often. Thus, plugs and stops should probably only be used on subsurface drainage systems that have been designed to minimize bypass and only then as an emergency measure when all other management options have been exhausted.

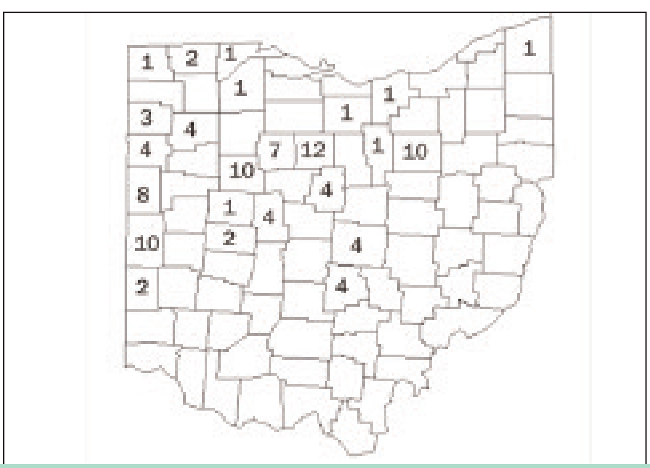

Figure 2.
Distribution of 98 incidents where animal wastes contaminated subsurface drainage effluent in the 88 counties of Ohio.

Table 2. Reasons why liquid animal wastes entered subsurface drains in Ohio (2000 to 2003).

Cause	Number of cases out of 98
Excess Rain or saturated Soils	41
Over application or application error	35
Manure storage management	33
Ponding manure or excessive irrigation	26
Drainage lines flowing or plug failure	20
Broken tile or shallow drainage	14
Equipment or storage failure	13
Dry, cracked soils	13
Feedlot runoff	11
Snowmelt	10
Eggwash water (thin waste, low solids)	10
Earthworm burrows	8

An alternative control measure is to permanently install shut-off valves and catch basins in the subsurface drainage system to capture any effluent before it enters the surface water supplies. Properly designed, these should be less prone to failure than drain plugs and stops alone. Additionally, they can serve as a tool for monitoring, managing, and cleaning up liquid wastes that get into subsurface drainage systems. Although this practice should help to control the problem when liquid wastes enter drainage systems immediately upon land application, this measure would be not practical when the drain lines are flowing at the time of application or when rainfall after waste application causes drain flow to occur and mobilizes waste-derived contaminants in the soil or drainage system. Currently, in Ohio, cost share funds are available for plugs and catch basins.

In conclusion

Although fish kills have declined dramatically in Ohio during the past 30 years, fish kills attributable to agriculture have increased during this time period. Most of the events attributable to agriculture are linked to livestock and manure management issues. Surface water contamination related to application of liquid animal wastes to soils with subsurface drainage systems has been a major contributor to this problem.

Our investigation of 98 animal waste spill records for 2000 thru 2003 indicated that while this problem has been noted in all regions of the state, most of the incidents occurred in northwestern Ohio where subsurface drainage systems and large confined animal feeding operations are common. Since soil, climatic, and farm operations in this area typify conditions in much of the Midwest, our results suggest widespread occurrence of this problem throughout the region.

In many of the cases, mismanagement and failure to have and follow a manure management plan probably contributed to the severity of the violation. Nevertheless, violations occurred even when approved procedures were followed.

The most common contributing factor was application to saturated soils or rain after application. Thus, a key component to reducing the number of violations is to avoid applying liquid wastes shortly before or after heavy rainfall and particularly when drain lines are flowing. Achieving this objective may entail increasing waste storage capacity, regular monitoring of amounts stored, and advanced scheduling of application equipment and custom applicators.

The next largest contributing factors were manure storage management and over application of liquid manure. Farm operators failed to adequately manage their manure storage structures or give themselves enough time to apply the manure in a timely manner.

While the results of our study and other research suggest that tillage and incorporation of liquid waste can reduce the potential for movement to subsurface drains in soil macropores, tillage is not a panacea. Violations occurred even when wastes were applied to tilled soil. The soil probably needs to be tilled to a seedbed condition to a depth of at least 3 inches (76 mm) before surface application or 3 inches (76 mm) below the depth of injection just before liquid wastes are applied in order to disrupt macropores and prevent preferential flow. This intensity of tillage is probably not practical in many situations and would have the undesirable consequence of eliminating the soil and water quality benefits of conservation tillage practices. Drain line stops should only be used as an emergency measure and in instances where the systems have been modified for their use.

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Figure 3.
Contamination of subsurface drainage effluent attributable to heavy rainfall following application of liquid swine manure to an untilled, corn silage field in Darke County, Ohio. Analysis of the effluent indicated a BOD_5 of 3200 mg/L, 205 mg NH_4-N/L, 9.0 mg NO_3-N + NO_2-N/L, and 174 mg total P/L. Courtesy of OEPA.

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