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Maximum Liquid Manure Spreading Rates on Sloping Land

Ron Fleming

University of Guelph, Ridgetown Campus, Ridgetown, ON, N0P 2C0

Malcolm MacAlpine

University of Guelph, Ridgetown Campus, Ridgetown, ON, N0P 2C0

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Abstract. *A field study was carried out in 2007 and 2008 to help establish maximum liquid manure application rates on sloping fields. In each year, liquid dairy and swine manure and water were spread on plots at 3 sites – representing slopes of 2 to 4%, 5 to 9% and greater than 9%. All soils were silt loam. Half of the sites were pre-tilled prior to application. Three rates of application were used, representing high rates (i.e. a worst case scenario). Rainfall simulation testing was carried out on a number of the 2007 plots - at 24 hours following manure application. Runoff from the 1 m wide plots was collected after manure spreading and again after simulated rainfall. In 2008, setback distances of 0 cm, 50 cm and 100 cm from the plot's lower edge were used to assess the potential for overland flow. Volume of runoff increased as slope increased. The volume of runoff for swine manure (avg. 2.6% DM) was significantly greater than for dairy manure (avg. 7.9% DM). Pre-tillage was effective at preventing any runoff liquid travelling 50 cm from the edge of the spread area for slopes up to 6.8% - this applied to all liquids and all rates. For greater slopes, runoff volumes at 50 and 100 cm setbacks were quite variable.*

Keywords. Setback, land slope, runoff, slurry

Background

Ontario's Nutrient Management Act (Government of Ontario, 2002) sets standards for maximum land-application rates of a variety of nutrient-rich materials. One of the goals is to avoid the over-application of nutrients to crop-land. Maximum application rates are calculated based mainly on the nutrient needs of the crops. However, in the case of liquid materials, there is also a risk of runoff at the time of application under certain conditions, if the application rate is too high. This runoff may reach surface waters and create unacceptable contamination. The liquids in question include liquid manure from different livestock types, as well as off-farm sourced "prescribed materials" (e.g. sewage biosolids).

The Nutrient Management Act uses information on the Hydrologic Soil Group (HSG), land slope and application method in establishing a maximum recommended application rate of livestock manure liquids. However, research was needed to better quantify the actual risk of runoff under a variety of conditions and field slopes. The goal was to protect the quality of nearby surface water.

The Prince Edward Island Ministry of Agriculture, Fisheries and Aquaculture recommends, in cases without incorporation, that no liquid manure be spread within 30 m of surface water on land slopes of up to 5%, and 60 m for slopes greater than 5%. The respective distances for "incorporated" manure are 10 and 30 m (PEI, 2006). Similarly, the Manitoba government has recommended setbacks from surface water when spreading manure. They consider land slopes of 0 to 4%, 4 to 6% and 6 to 12%. They also distinguish between manure that is not incorporated, manure that is incorporated within 48 hours, and injected manure. Setback distances range from 5 to 90 m (Manitoba, 2001). Both provinces use land slope to establish setback distances to surface water for manure spreading, rather than adjust maximum application rates near surface water.

Runoff vs infiltration

Infiltration is defined as "the process by which water enters the soil pore spaces and becomes soil water" (Brady and Weil, 1999). At the start of a rainfall, the rate of infiltration (i.e. infiltration capacity) typically is high when the soil is dry, and drops until a steady state condition is reached. This process is mainly affected by the soil texture, the presence of vegetation and/or surface residues, soil compaction and the presence of soil macropores. Also, when rain falls on bare ground, the surface of many soils will form a seal – due to compaction caused by the energy in the rain drops. This also reduces infiltration for subsequent rainfalls.

When the application rate of liquid exceeds the infiltration capacity of the soil, ponding on the surface begins. Depending on land slope, the liquid eventually starts to move across the land surface. This runoff of liquid is what we are trying to avoid when spreading liquid manure or other liquids onto the field. On sloping land, in addition to the factors already mentioned, runoff can be reduced by tilling across the slope rather than up and down the slope.

Maximum application rates

Various studies have been carried out that have helped identify the key components that could impact the risk of runoff of manure from farm fields.

- **Soil texture** – Texture impacts drainage and is a main component of the Hydrologic Soil Group rating system.
- **Soil structure** – Additions of organic matter (including livestock manure) to the soil have been shown to improve soil structure through aggregation, thus improving the downward flow of water through the soil profile (Boyle et al., 1989). Madramootoo and Enright (1990)

found more runoff in the compacted wheel tracks resulting from field operations in a potato field. They also measured an increase in infiltration capacity once the soil was tilled.

- **Land slope** – Runoff amounts will be greatest on sloping soils having low infiltration rates, or on frozen soils (Czymmek et al., 2005). Abu-Ashour and Lee (1999) applied a bio-tracer to the surface of the soil in plots having slopes of 2% and 6%. Natural rainfall (26 mm) occurred 2 days later. The tracer was found as far away as 20 m (from the centre of the 10 by 10 m plots) for the 2% slope and 35 m for the 6% slope. Rieke-Zapp and Nearing (2005) measured erosion losses from complex slope shapes. The uniform, nose and convex-linear slopes yielded more sediment than the concave-linear and head slopes.
- **Soil management** – Runoff volumes are significantly greater for "conventional tillage" systems (including moldboard plough, disc-harrow and culti-packer) than for no-till systems (Angle et al., 1984; Azooz and Arshad, 1996).
- **Vegetative cover** – Vegetation helps absorb the energy from rain drops, and also slows down water movement over the soil surface, increasing infiltration.
- **Soil moisture level** - The antecedent soil moisture affects runoff. A study in Ireland found that the summer infiltration rate was, on average, 3.5 times the winter rate. The risk of overland flow resulting from heavy rains was deemed to be very small in summer, at least on well-drained soils that were not subject to soil compaction by heavy machinery traffic (Diamond and Shanley, 2003).
- **Risk of rainfall after spreading** – see later discussion
- **Frost in soil** – Because the risk of runoff is greater, spreading of manure on frozen or snow-covered ground is not recommended.
- **Manure moisture level** – This is discussed later.
- **Rate of application** - The intensity (i.e. mm/hr) and duration of rainfall are important in assessing the risk of rainfall runoff. Liquid manure is generally applied at comparatively low rates (e.g. not normally exceeding an average depth of 6 mm), but applications tend to be of high intensity and short duration.
- **Application method** – Ross et al (1979) found that the rate of surface runoff from plots where liquid manure was injected was less than half of the rate for plots where manure was surface-applied. Injection virtually eliminated any pollutant yield, compared to the surface application. There may be a concern that incorporating the manure disturbs the soil surface to the extent that there will be increased loss of soil and soil P if heavy rains occur soon after. Tabbara (2003) compared runoff from incorporated vs surface applied manure and fertilizer, after a simulated rainfall. Total suspended solids (TSS) concentrations in the runoff were higher but concentrations of dissolved reactive phosphorous (DRP) and total phosphorous (TP) were 30 to 60% lower for the incorporated sites.

Impact of rainfall after application

When applying liquid materials to the soil, there is a risk of runoff at the time of application. However, there is also a risk that rainfall occurring soon after application will cause runoff. Ross et al (1979) found that the longer the period of time between manure application and rainfall, the lower the risk of contamination in the runoff. A one-day delay reduced the concentration of contaminants by at least 80%, compared to rain two hours after manure application.

Patni et al (1985) applied manure (DM in range 7 to 9%) at rates of 90 to 110 m^3/ha to fields having an average slope of 0.1%. The manure was ploughed into the soil immediately after application. Neither the presence or absence of manure application activity nor the extent of tile drainage in the watershed had an effect on the bacterial quality of the runoff.

Giddens and Barnett (1980) applied poultry litter at various rates to a sandy loam soil on a slope of 7%. The test was carried out using small plots and a rainfall simulator. Additions of the dry poultry litter (25% moisture) to the soil led to a reduction in the volume of runoff from the plots and reduced or eliminated soil loss from the plots.

In a study using soil columns, Roberts and Clanton (2000) examined the impact on soil sealing of simulated rainfall and the application of swine and dairy manures. They found that a stable surface seal developed after a 30 minute rainfall in Waukegan silt loam soil (and after 4 such rainfalls in Hubbard loamy sand). Surface application of manure, with no incorporation, caused short-term plugging in the Hubbard loamy sand. However, when dairy manure was applied to the Waukegan silt loam, the infiltration capacity immediately improved to a level higher than the soil's initial infiltration capacity.

Edwards and Daniel (1991) spread poultry litter and liquid poultry manure onto small plots. The land slope was 5% and the soil was a Captina silt loam. By varying application rates and following up 24 hours later with different amounts of simulated rainfall, they discovered that the manure type had an impact on infiltration and runoff. Runoff was highest from the plots receiving liquid layer manure – total manure application rates were not given. Their interest was in finding the appropriate Runoff Curve Number (CN) to use in the SCS formula to predict runoff from the plots.

Gessel et al. (2004) used natural rainfall events over a 3 year period to study the impact on runoff of incorporating liquid swine manure into the soil. Manure was applied at 0.5, 1.0 and 2.0 times the agronomic rate recommended for the site (growing corn and soybeans). The 12 plots were on land with a 12% slope. There were 16 runoff events in total and five of these showed a significant effect of manure application rate. In each of these five cases, runoff was less for the "2.0X" manure rate than for the other rates. The improvement in infiltration rate was not observed at low rates of liquid manure application. In a rainfall simulation study, Wang et al. (2000) also looked at differences in runoff between incorporated and broadcast manure. Surface broadcasting of liquid swine manure resulted in significantly higher *E. Coli* and Fecal *streptococcus* bacteria concentrations in surface runoff water (compared to incorporation).

Objectives

A two-part project was designed to develop maximum liquid manure application rates. This report deals with the portion of the study that used field trials on different hydrologic soil groups of the province and during different seasons of the year. All four of the overall objectives were addressed, at least in part, by this field study. The other part of the study focused on using the existing SCS method for runoff estimation.

Overall objectives were:

1. Develop and evaluate science-based maximum land application rates for liquid manure.
2. Assess the impact of post application rainfall events on runoff on different field slopes representative of hydrologic soil groups of Ontario.
3. Propose maximum land application rates on pre-tilled and untilled land surfaces for soils and slopes of Ontario for typical liquid manure types.
4. Make relevant recommendations to minimize the risk of surface water contamination.

Study Setup and Procedures

Experimental Design

The field trials were carried out in the summers of 2007 and 2008. This represented the conditions under which a significant amount of manure is spread in Ontario – i.e. onto wheat fields following the summer harvest. The experiment in each year was designed to look at a particular Hydrologic Soil Group (preferably a C or D) and three different land slopes. Target land slopes were in the following ranges: 3 to 5%, 6 to 8%, 9% and greater. Runoff was not expected for slopes under 2%.

Three liquids were chosen for application: water, liquid dairy manure (having a DM in the range 5 to 8%), and liquid swine manure (having a DM in the range 2 to 5%). These liquid treatments were surface-applied to the land at three application rates. Half of the plots were pre-tilled.

In the 2007 study, rainfall simulation trials were run on approximately two thirds of the plots. This took place one day after the manure (and water) application. Any rainfall-induced runoff was then captured and measured.

Site Selection

In each of the two years, three fields that satisfied the slope and texture conditions were found - one for each slope range. In selecting these field sites, consideration was given to: uniformity of soil texture and landscape features, slope uniformity, soil structure, tillage management, and crop residue cover. Soil characteristics and crop management details were recorded for each site.

Site Preparation

At each of the sites, general plot locations were established. Half the site was then tilled with a set of tandem disk harrows (wheel-mounted pull hitch). Corners of the individual plots were marked and installation of the plot boundaries began. In 2007, 54 plots were established at each of the three sites (not all were used at Site 07-1, however). Based on the 2007 results, the study was amended for 2008, when 162 plots were established at each site.

For each plot, the land slope was measured. A wooden board (length = 1 m) was laid in the middle of the plot, sloping downhill. A ruler and level were then used to measure the drop from the higher to the lower edge of the plot.

Plastic boundaries were set into the ground at each plot. In 2007, the plots were one meter wide by one meter long (see Figure 1). For reasons discussed later, the 2008 plots were each one meter wide by four meters longs (i.e. running up the slope). During the 2008 testing, manure was applied to a three meter length of each plot and "setback from the lower edge" was included as a treatment - there was a setback of 0 cm, 50 cm and 100 cm from the lower edge of the plots (see Figure 2).

The boundaries prevented any liquid from entering the plot area by overland flow. They also ensured that any runoff from the plot was channeled to the down-slope edge. At this lower edge, a galvanized steel trough was sunk into the ground. Any runoff spilled over the metal lip and into the trough. It ran down an incline and into a plastic tub (either 5.0 or 5.8 L capacity) which was sunk into the ground.

For the 2007 study, this plastic tub was fitted with a lid, to ensure that the only way liquid could enter was through a funnel. In addition, a rigid plastic sheet was used to cover the hole in which the tub was located. This ensured that manure could not enter the hole as the spreader passed over. In a similar way, a strip of rigid plastic laid over the metal trough ensured that only runoff could enter the trough – i.e. not manure dropping from the spreader's drop pipe. Because manure was applied in a different way in 2008, no covers were needed.

Figure 1 Plot configuration in 2007 study, showing boundaries and covers over the collection trough and tub

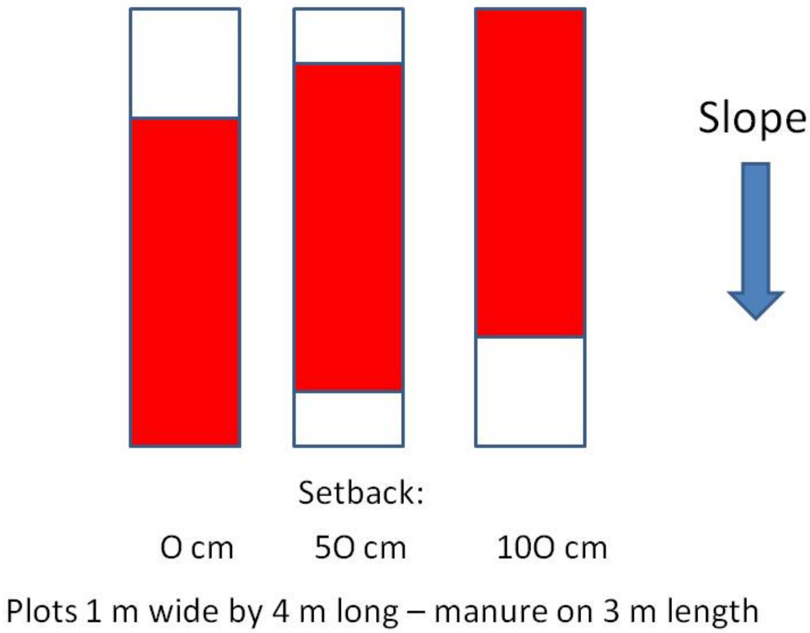

Figure 2 Plot layout in 2008 study

In 2007, soil samples (15 cm deep) were collected from around the outside of each plot. These samples were used to establish pH, N, P, K and Mg for the soil at each plot. Fewer samples were collected at each site for the 2008 study.

At each of the three sites, in both years, soil bulk density was measured. Surface vegetation was estimated with the use of a standard length of rope containing 50 evenly-spaced knots. The rope was dragged to a random location and dropped. The soil was considered to be covered with vegetation every time a knot touched plant material (alive or dead). In this way, an average vegetative cover (%) was calculated.

To establish soil texture, two composite samples were collected for each site – one for the tilled portion and one for the non-tilled portion. To establish the soil moisture conditions on the day of initial liquid application, composite soil samples were collected for each of the three sites – for the tilled and non-tilled portions of the study area. Similarly, the soil organic matter was measured using composite samples for each tillage treatment at each site.

Initial Liquid Application

The liquid manure types were chosen to represent average nutrient and dry matter content values listed in Ontario's NMAN program. The liquids were applied at three different rates: 46.7, 93.5 and 140.2 m^3/ha (equivalent to 5000, 10,000 and 15,000 US gallons per acre). These were chosen to represent a range of high application rates. In the 2007 study, nutrient management plans were calculated for the three sites to establish typical recommended rates for the various sets of conditions.

The sources of dairy and swine manure and water were the same for all sites in both years of the study. The water came from a nearby pond.

In 2007, a tank spreader was used to apply the liquids. It was set up to move across the slope and it straddled the plots as it moved. Once the spreader was calibrated for the desired rates, only the tractor speed was altered. The spreader settings and the PTO speed were held constant. After the spreader cleared each plot, the tractor was stopped, the new speed selected and the spreader was started again for the next plot.

In 2008, all liquids were applied manually. Plastic pails containing a precise volume of liquid were carried to each plot. The application rate needed for each plot determined how many pails were needed. The liquids were applied by simply pouring from the pails. This ensured an even and accurate application at each plot.

Runoff Collection – Initial Liquids

Following the initial application of liquids, a period of at least one hour was allowed for any runoff to occur. Liquid in the plastic container was then poured into a clean graduated cylinder for a volume measurement. A sample of up to 250 mL was then extracted and refrigerated, for later analysis. Levels of Total Kjeldahl Nitrogen (TKN), total Phosphorous (P), total Potassium (K), pH, Dry Matter (DM) and ammonium-nitrogen (NH_4-N) were measured for each sample. For measurable runoff volumes less than 10 mL, the volume was recorded but no sample was submitted for analysis.

Rainfall Simulation

In 2007, rainfall simulators were set up for approximately 2/3 of the plots. These tests were intended to simulate the impact of a major rainfall event shortly after the application of manure. Rainfall studies were carried out on the day following the manure and water application. The elapsed time was in the range of 18 to 24 hours following manure application.

The intensity and duration of rainfall were based on the five year return period for the area. For a rainfall duration of 30 minutes, a five-year return period for London, Ontario would have an intensity of 51 mm/hour (Prodanovic and Simonovic 2004). The FullJet nozzle, 3/8 HH-SS 24W (by TeeJet), was used. It was mounted on a tripod and arm assembly (see Figure 3). The nozzle was located above the centre of each plot, at a height of 1.5 m. This nozzle had a wide spray angle of 110^o and a flow rate of 134 mL/sec when the water pressure was maintained at 48.3 kPa (i.e. 7 psi). Water from the pond was transported to a large plastic water tank close to the plots. Two water pumps were used to maintain pressure in the system, and up to nine rainfall simulators were run simultaneously. Workers kept up constant monitoring of the system, mainly ensuring that the pressure was correct. A rain gauge was placed in the ground adjacent to one of the plots, as a way to ensure the rainfall amount was as desired.

Runoff Collection – Simulated Rainfall

The same setup was used to collect this runoff as for the initial runoff. In preparation, the collection trough was cleaned out. The plastic containers and funnels were all washed with soapy water, rinsed with potable water and then air-dried. All plastic covers were re-installed. At one hour following simulated rainfall, the process of measuring runoff began. Similar to the procedure described earlier, runoff water was poured in to a clean graduated cylinder to measure the volume. The priority was to collect a sample (approx. 200 to 250 mL) for nutrient analysis (TKN, P, K, pH, DM and NH_4-N). However, when the volume of sample was great enough, a separate water sample was bottled for measurement of *E. coli*. These samples were refrigerated and delivered to the testing lab within 24 hours.

Figure 3 Typical rainfall simulator test setup

Summary of Treatments Used

Tables 1 and 2 give a breakdown of the various treatments used in the study and numbers of plots for each year.

Table 1 – Treatments used in 2007 study

Factors	Number	Details
Liquid applied	3	Swine, dairy, water
Land slope	3	3 to 5%, 6 to 8%, > 9%
Application rate	3	46.7, 93.5 and 140.2 m^3/ha
Tillage	2	Un-tilled vs tilled
Replications	3	
Total plots	162	

Table 2 – Treatments used in 2008 study

Factors	Number	Details
Liquid applied	3	Swine, dairy, water

Land slope	3	3 to 5%, 6 to 8%, > 9%
Application rate	3	46.7, 93.5 and 140.2 m^3/ha
Tillage	2	Un-tilled vs tilled
Setback	3	0 cm, 50 cm, 100 cm
Replications	3	
Total plots	486	

Results and Discussion

Site Conditions

It proved to be rather difficult to find suitable field sites having slopes greater than 9% while representing Hydrologic Soil Group D. For practical purposes, soils in Group C were selected. In 2007, sites 07-2 and 07-3 were in the same field and Site 07-1 was on a nearby farm. The three sites in 2008 were near the 2007 sites. Once again, the two steeper sites were in the same field (located about 4 km from the sites used the previous year). Site 08-1 was on the same farm as Site 07-1, but in a separate field. Background information and measured conditions at the six sites are summarized in Table 1. Soil map information suggested that the predominant soil type at Site 07-1 was Muriel silty clay loam - Hydrologic Soil Group C (OMAFRA 1997). Similarly, the soils at Sites 07-2 and 07-3 were designated as predominantly Bennington silt loam ranging to Muriel, making the HSG in the B to C range. The predominant soil type at all three sites in 2008 was Muriel silty clay loam (i.e. listed in OMAFRA 1997 as HSG = C).

As shown in Table 1, soil test results for the sites revealed the texture to be Silt Loam. Soil Organic Matter (OM) was lowest at the site where the slope was greatest, in both years (i.e. 07-3 and 08-3). OM was highest at Site 1 in both years. The fact that the slope was lowest may have had an influence, though it appeared to be due to land management practices adopted by the farm operator. The percent vegetative cover was fairly high for the three sites in each year, and was lower for the recently tilled plots. All six sites had a ground cover of wheat stubble. In addition, the three sites in 2007 and site 08-1 were under-seeded with red clover. Unfortunately, a set of field notes containing data on the vegetative cover for Site 07-3 was accidentally destroyed. The vegetative cover was assumed to be similar to Site 07-2, which was nearby in the same field.

Table 1 - Site conditions at time of first liquid application for the 6 sites

Site	Pre-Tilled	Soil Moisture (%)	Soil OM (% dry)	Vegetative Cover (%)	Soil Texture	Bulk Density (g/cm^3)	Land Slope (%)
07-1	No	22.4	3.5	92	Silt loam	1.19	2.9
07-1	Yes	24.4	4.1	56	Silt loam	1.19	2.7
07-2	No	16.4	2.6	77	Silt loam	1.06	5.3
07-2	Yes	16.3	2.4	62	Silt loam	1.06	4.7

07-3	No	18.9	1.8	77*	Silt loam	1.48	15.2
07-3	Yes	18.6	1.6	62*	Silt loam	1.48	15.0
08-1	No	20.4	4.0	96	Silt loam	1.17	2.5
08-1	Yes	21.0	3.9	79	Silt loam	1.17	3.0
08-2	No	14.7	1.8	86	Silt loam	1.35	6.8
08-2	Yes	14.4	1.7	58	Silt loam	1.35	6.5
08-3	No	16.7	1.6	87	Silt loam	1.39	9.2
08-3	Yes	17.0	1.5	58	Silt loam	1.39	10.2

* Field notes were lost and amounts are assumed to be similar to site 07-2, which was nearby in the same field

At any specific site, there was a certain amount of variability in vegetative cover in the field. This was not as noticeable in the 2007 tests, where the crops were planted across the slope. However, it was more obvious in 2008 at sites 08-2 and 08-3, where the crops were planted (and harvested) up the slope. There were bands of more dense surface cover, apparently directly behind where the combine had recently travelled. Even though straw had been harvested from these two sites, a carpet of chaff typically covered the ground at a width corresponding to the combine width. A number of the plots had only the remaining vertical stalks of the wheat and bare ground, while others were covered with a thin layer of this chaff. Most plots were somewhere in between these two extremes. Later analysis of runoff volumes for the plots, taking this variability in vegetative cover into account, was not able to show significant differences in runoff.

Table 2 gives mean values for soil nutrient levels at each of the sites. The 2007 values were used in calculating the “recommended” application rates using Ontario’s Nutrient Management Planning software, NMAN. Results of this analysis are discussed in the following section.

Table 2 - Soil sample analysis results (on a Dry Matter basis)

Site	N (%)	P (mg/L)	K (mg/L)	pH
07-1	0.20	17.4	126	7.5
07-2	0.13	9.8	88	6.8
07-3	0.10	7.1	81	7.8
08-1	0.22	9.2	101	6.6
08-2	0.11	32.0	135	7.8
08-3	0.10	20.3	100	7.8

Tillage and Application of Liquids

The dates of the tillage and liquid applications for the sites are recorded in Table 3. In 2007, the steepest sloping site, Site 07-3, was the first to be completed. However, tillage for all three sites was done at the beginning of the field setup operation. As a result, several days had elapsed between tillage and the application of liquids, especially at Site 07-1. Natural rain fell during this time – 20 mm total on August 19 and 20, 4 mm on August 22, 27 mm on August 26 and a small amount on September 11. In 2008, an attempt was made to minimize the number of days between the tillage operation and the day of application - to reduce the risk of large amounts of rain falling on the tilled sites prior to running the study.

At Sites 07-2 and 07-3, 54 plots were used for the initial application of manure or water. This represented: 3 liquids x 3 application rates x 3 replications x 2 tillage practices, for each site. Rainfall simulation studies were then carried out on 2/3 of these plots – i.e. 36 plots the following day. Logistical problems prevented the use of this number of plots at Site 07-1, however. The initial water application was dropped for this site – results from Sites 07-2 and 07-3 (i.e. the two steeper sites) were deemed to be sufficient. The 36 plots were comprised of: 2 liquids x 3 application rates x 3 replications x 2 tillage practices. Only those plots receiving 46.7 m^3/ha of manure (i.e. the lowest rate) were used for the rainfall simulation, plus four plots that had received no manure (two for each tillage condition). This gave a total of 16 plots for the rainfall simulation study for this site. In the 2008 study, all 486 plots in the experimental design were used.

Table 3 - Dates of site tillage and liquid application

Site	Tillage Date	Liquid Application date	Rainfall Simulation Date
07-1	Aug. 16, 2007	Sept. 12, 2007	Sept. 13, 2007
07-2	Aug. 15, 2007	Aug. 30, 2007	Aug. 31, 2007
07-3	Aug. 15, 2007	Aug. 27, 2007	Aug. 28, 2007
08-1	Aug. 19, 2008	Aug. 22, 2008	Not done in 2008
08-2	Jul. 29, 2008	Aug. 8, 2008	Not done in 2008
08-3	Jul. 29, 2008	Aug. 14, 2008	Not done in 2008

The rates of application of liquids were as listed earlier – i.e. 46.7, 93.5 and 140.2 m^3/ha. These rates were chosen somewhat arbitrarily to represent high or very high applications. It was assumed that the highest rate of application used in the study would never actually be allowed, from a nutrient management standpoint. To test this, the Nutrient Management Computer Program, NMAN 2.0.1 (OMAFRA 2007), was used to calculate the maximum application rates for applying liquid dairy and swine manure to each of the plots in the 2007 study. The cut-off point for these calculations was what is referred to as a Best Management Practice (BMP) red flag.

Table 4 gives the maximum rates that could have been applied under the various conditions before this BMP red flag appeared. The assumption is that when a BMP red flag application rate is exceeded, the farmer is applying more manure than is recommended. These high application rates are deemed to pose an unacceptable risk of causing environmental harm or economic loss.

Table 4 - Maximum manure application rates allowed before NMAN software gives a BMP Red Flag

Site	Pre-Tillage	Manure Type	Maximum Application (m^3/ha)
07-1	No	Dairy	75
07-1	Yes	Dairy	100
07-1	No	Swine	75
07-1	Yes	Swine	100
07-2	No	Dairy	100
07-2	Yes	Dairy	130
07-2	No	Swine	100
07-2	Yes	Swine	130
07-3	No	Dairy	50
07-3	Yes	Dairy	75
07-3	No	Swine	50
07-3	Yes	Swine	75

Based on the Table 4 values, the lowest rate of application would have been acceptable in all cases. Similarly, the highest rate would not have been acceptable in any circumstance. The medium rate would not have been allowed on the steepest sloping site.

Runoff or No Runoff

There were problems in getting useable runoff data at a few of the individual plots. For example, in 2007, the tractor ran over part of the edge of a few plots. In 2007, there were a few cases where manure outside of the plot interfered with the sample collection. In both years, there were cases where the collection system was overwhelmed by the volume of runoff (e.g. collection tub not quite large enough). Also, the dairy manure was much thicker than the swine manure or water and tended not to flow, no matter how high the application rate. It sometimes would not run through the collection trough. Or it would plug the large funnel that was initially used in the 2007 tests to transmit liquid from the trough to the collection tub. Despite these problems, most of the plots yielded valid data. As expected, several of the sites yielded no runoff and others did not yield enough for a sample to be submitted (only the volume was recorded for 10 mL or less).

In the 2007 study, following the first application of manure or water (total of 144 plots), measureable runoff occurred at 108 plots. There was no runoff at 36 plots (i.e. at 25% of plots there was no runoff). Surprisingly, pre-tillage had no impact on this number. For plots receiving tillage, 18 generated no runoff and 54 generated runoff. These numbers were identical to the non-tilled plots.

As the 2007 study was taking place, it appeared that at least a portion of the liquid entering the collection trough and tub was due to splashing of liquid during application. The drop nozzles on the spreader directed the manure (or water) downward under pressure. When it hit the ground, the lateral movement appeared to be a result of both runoff and the splashing due to the force of application. Even though the collection troughs were covered with a strip of plastic, this splashing during application appeared to have an impact on whether or not runoff occurred at some plots. It also likely influenced the total quantity of runoff on a number of plots.

In response to the concern about application method affecting what happens at the edge of the spread pattern, the 2008 study was set up so that liquid application was carried out by hand, as mentioned earlier. This allowed for a more even application. It allowed for more accurate placement of liquid along the down slope edge of each plot. It greatly lowered the potential for lateral movement due to splashing. Finally, it allowed for plots of longer dimensions. This is shown in Figure 4.

In 2008, measureable runoff occurred on 136 of the 486 plots (i.e. 28%). For Site 08-1 there were 24 plots with runoff. In four of these cases, the runoff volume was less than 10 mL. However, one tub overflowed. For Site 08-2, there were 39 plots with runoff. Four tubs overflowed and in two cases, the collection troughs overflowed. For Site 08-3, there were 73 plots with runoff. At this steeper-sloped site, seven tubs overflowed. In the cases where the tubs overflowed, the maximum volume of the tub was assumed as an approximation of runoff volume, discussed next.

Figure 4 Manual application of liquid manure - 2008 study

The results for 2008 are considered to be more reliable, simply because of the more accurate method of applying manure and the minimizing of the lateral splashing of manure (or water) at the time of application. The difference between the two years is not quite as dramatic as these numbers suggest. If only those plots with a setback of 0 cm are considered (i.e. 1/3 of the plots in 2008 vs. all plots in 2007), 82 of 162 (51%) generated measureable runoff in the 2008 testing.

Volume of Runoff

a) Impact of Site/Slope

As mentioned, at some plots, due to problems with sample collection or short-circuiting, runoff volume could not be accurately measured. For the 2007 testing, based on the 135 plots with accurate data, the mean volumes of runoff per plot were: 70.5, 386 and 635 mg, respectively for Sites 07-1, 07-2 and 07-3. The volume of runoff per plot at Site 07-3 (steepest slope) was significantly higher than that for Site 07-1 (P=0.01). However, the mean runoff volume from plots at Site 07-2 was not significantly different from the other two sites (using Fisher's LSD at 95% confidence level).

In 2008, the mean runoff volume for all plots was 767 mL. Differences in runoff volumes were affected by site – with runoff volume increasing significantly as slope increased (for both pre-tilled and un-tilled plots). A summary of mean runoff volumes for the three sites used in 2008 is shown in Table 5.

b) Impact of Pre-Tillage

Somewhat surprisingly, pre-tillage of the plots did not have a significant impact on the volume of runoff from the plots in 2007. From all pre-tilled plots, the mean runoff was 309 mL. This compares to 523 mL for the un-tilled plots, but the difference was not significant (P = 0.14). When the 3 sites were examined individually, the same pattern was observed – the mean runoff was greater for un-tilled plots but there was so much variability that the relationship was not significant. Similarly, when "liquid applied" was considered (in conjunction with tillage), there was no significant difference between swine, dairy manure or water. Tillage had no significant impact on runoff volume, even when the three application rates were considered separately.

The results for 2008 were different, however. For pre-tilled plots, the mean runoff volume was 326 mL which was significantly lower than the 1210 mL average for the un-tilled plots.

Table 5 – Summary of mean runoff volumes from the plots in 2008

	Mean Runoff Volume (mL)	Runoff from Pre-tilled plots (mL)	Runoff from Un-tilled plots (mL)	Significance: Pre- vs Un-tilled?
Site 08-1	123	71	176	no
Site 08-2	585	80	1090	yes
Site 08-3	1590	828	2360	yes

c) Impact of Liquid Applied

The volume of runoff was affected by the liquid applied. Table 6 summarizes mean runoff volumes. In both years, the runoff volume was significantly higher for plots receiving swine manure than for plots receiving dairy manure. In 2007, the runoff from plots receiving water was not significantly different from either swine or dairy. However, in the 2008 study the volume of runoff from the plots receiving water was significantly higher than the dairy manure plots and significantly lower than the runoff from the plots receiving swine manure. These relationships are shown in Figures 5 and 6. For comparison, Table 6 includes the results for the "0 cm" setback (most similar to the 2007 study). The differences between the two years were most likely influenced by differences in average slopes, application methods and the total volume applied (rates were the same but three times the total volumes were applied to plots in 2008).

Table 6 – Summary of mean runoff volumes (mL) from the plots for the three liquids applied

	Liquid Applied		
	Swine Manure	Water	Dairy manure
2007 Sites	701	392	191
2008 Sites	1440	852	20.1
2008 Sites: setback = 0 cm	1990	1170	34.1

One of the reasons water was chosen as a liquid treatment in this study was to provide a basis for comparison with liquid manure. Many more runoff studies have concentrated on water runoff. The expectation was that swine manure, with its typically low dry matter content, would behave in a similar fashion to water. What the study found was that there is a slightly greater tendency for runoff for swine manure than for water. This phenomenon was recorded by Unc and Goss (2006). They found that liquid swine manure had a tendency to block smaller surface pores. Especially in finer textured soils, this had the potential to create more macropore flow, but it also led to an increased amount of surface runoff.

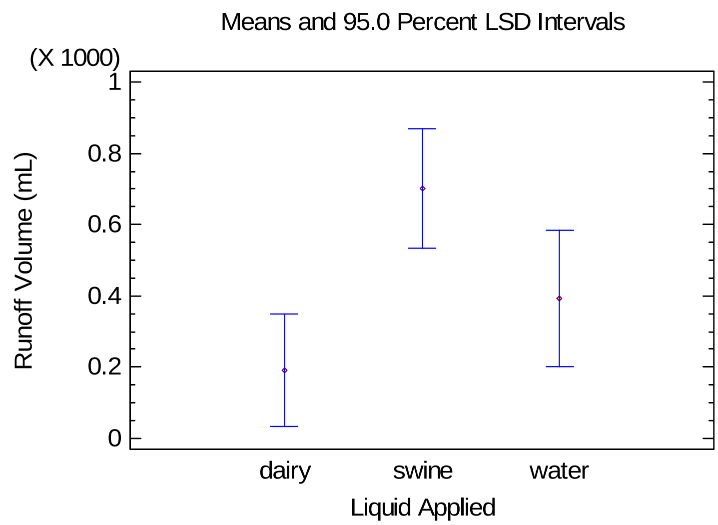

Figure 5 Mean runoff volumes for the three liquids applied to plots in 2007

d) Impact of Application Rate

As expected, the rate of application had an impact on runoff volume. Table 7 lists mean runoff volumes for the various application rates. In 2007, the highest rate of application resulted in a significantly higher volume of runoff than the other two rates. In 2008, the lowest application rate yielded the least runoff, which was significantly less than the runoff from the middle application rate. It, in turn, yielded significantly less runoff than the high application rate. This relationship held true for the plots with Setback distance = 0 cm (the case that was closest to the 2007 conditions).

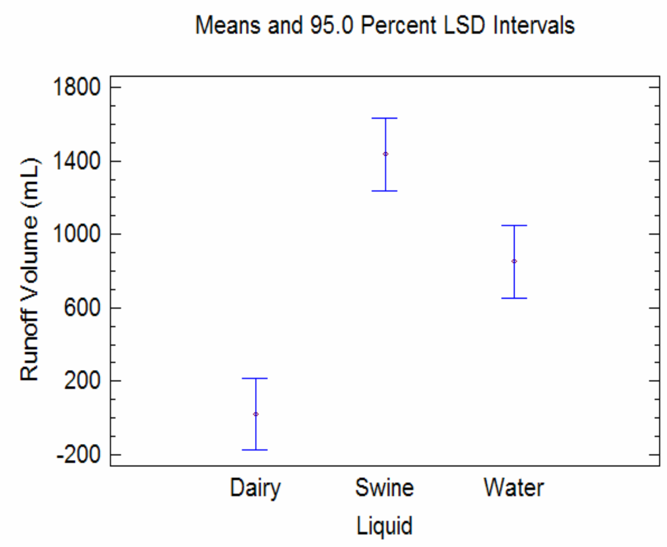

Figure 6 Mean runoff volumes for the three liquids applied to plots in 2008

Table 7 – Summary of mean runoff volumes (mL) from the plots for the three application rates

	Application Rate		
	47 m^3/ha	94 m^3/ha	140 m^3/ha
2007 Sites	97.0	253	963
2008 Sites	181	677	1440
2008 Sites: setback = 0 cm	280	1130	1730

e) Impact of Post-Application Simulated Rainfall

The volume of runoff following simulated rainfall was not influenced by the type of initial liquid applied in the 2007 study. The mean runoff from plots that had received dairy manure was 867 mL; from swine manure plots was 868 mL; and from watered plots was 942 mL – these were not significantly different. There was, however, an impact of Site on rainfall runoff. The mean runoff from the plots at Site 07-2 (mean = 1260 mL) was significantly higher than the rainfall runoff at the other two sites (Site 07-1, mean = 293 mL; Site 07-3, mean = 687 mL).

The initial rate of application (i.e. of water, swine manure and dairy manure) had an impact on the volume of runoff after simulated rainfall. The mean rainfall runoff from the plots receiving liquid at the highest rate (i.e. 140 m^3/ha) was 1630 mL. This was significantly higher than the runoff from the plots that had originally received 94 m^3/ha (mean rainfall runoff = 929 mL) and the plots that had received 47 m^3/ha (mean rainfall runoff = 371 mL).

f) Impact of Setback Distance

As expected, the mean runoff volume was greatest for those sites where the setback distance was 0 cm (i.e. manure or water was applied adjacent to the downslope reception trough). The volumes are summarized in Table 8. When all plots were considered, the volumes of runoff for setbacks of

50 and 100 cm were significantly less than for a setback of 0 cm. At Site 08-1, none of the applied liquids moved the 50 cm (or 100 cm) to the collection trough.

At Site 08-2, the runoff volume for a setback of 100 cm was significantly less than for a 0 cm setback, but neither was significantly different from the 50 cm setback. For Site 3, there were no significant differences in runoff volume as setback distance varied.

Table 8 - Summary of mean runoff volumes (mL) at each site (in 2008) from the plots for the three setback distances

	Mean	Setback = 0 cm	Setback = 50 cm	Setback = 100 cm
Site 08-1	123	370	0	0
Site 08-2	585	1070	536	147
Site 08-3	1590	1760	1390	1630
Overall	767	1070	647	589

The greatest amount of runoff at Site 08-2 was for swine manure spread at the highest rate onto soil that had received no pre-tillage. Water spread at the highest rate onto un-tilled soil also resulted in high runoff, as did swine manure at the middle rate spread on un-tilled soil. There was no runoff of dairy manure at Site 08-2. Further, there was no runoff for either the 50 cm or the 100 cm setback at Site 08-2 on any of the pre-tilled plots (i.e. for any of the 3 liquids applied).

Pre-tillage could not be counted on at Site 08-3 to eliminate the travel of the swine manure or water. A small amount of dairy manure was able to travel the 100 cm over un-tilled soil. The pattern for the other liquids, especially at the middle and highest rates was less clear. The slopes at this site (average of 9.7%) and the application rates were great enough that runoff flow was unpredictable. In most cases, the flow was not sheet flow (i.e. a thin layer of liquid moving uniformly down the slope). Rather, the liquid formed rills and a more concentrated flow resulted (see Figure 7). Most of the land that did not receive liquid (in this setback zone) remained dry. Any depressions in the field served as channels for the liquid. For the un-tilled plots, this mainly included rills that had been previously formed by rainfall runoff.

For the 2008 study, a calculation was made to express the volume of runoff liquid as a percentage of the volume of liquid applied to each plot. There was a significant difference between the three sites. These values for Sites 08-1, 08-2 and 08-3 were 0.39%, 1.8% and 5.0%, respectively. Because manure (and water) was spread up to 4 m upslope of the lower collection trough at each plot, we can conclude that at Site 3, where the average land slope was 9.7%, an average of 5% of the liquid applied ran off the surface of the land for a distance of up to 4 m. Unfortunately, the study was not able to establish the maximum distance this runoff might have travelled. It was able to show the drop off in volumes between the 0 cm setback and the 50 and 100 cm setbacks, discussed above and most evident at Sites 08-1 and 08-2.

g) Impact of Spread Area

The 2007 study used a spread area that was 1 m x 1 m and the 2008 study area was 1 m x 3 m. The same application rates were used (i.e. volume per unit area) so in the 2008 study, three times the quantity of liquid was applied to each plot. Part of the rational for this was to examine the cumulative impact of runoff over a longer slope length. Tables 6 and 7 give comparisons of runoff volumes between the two study years. It appears that roughly twice the volume of runoff resulted from the 2008 conditions. Between the two years, the liquids were similar, the application rates were identical, the soils were the same, the slopes were similar (but not identical), the pre-tillage and crop management were similar. The application methods were different, and the 2008 study was expected to yield less runoff because of the improved application method. There were some differences in vegetative cover between the two years and the 2008 study used 3 setback distances. It seems reasonable to conclude that at least a portion of the greater volume of runoff in 2008 was due to the fact that three times the volume of liquid was applied to each plot and there was some cumulative impact of runoff from the wider spread area. This suggests that the maximum runoff distance was greater than 1 m.

Figure 7 Runoff between crop rows at Site 08-3 for a 100 cm setback

Runoff Quality

Tables 9 and 10 give a summary of properties of the various liquids that were applied at the three sites, and the resulting runoff. The measured properties of the liquid inputs, including concentrations of nutrients, were in the expected ranges. The Dry Matter content of the three applied liquids was significantly different. There were small differences from one spreading day to the next, even though the same three sources were used throughout the study. Similarly, there were differences from the first to the second year, even though the same three sources were used. These differences were most likely the result of a different level of agitation prior to removal of the manure from storage. For each set of numbers (i.e. 2007 and 2008), the Standard Deviation values were fairly small, indicating consistency in the properties of the input liquids. The same was not true for the runoff.

Table 9 – 2007 study - Mean values of selected measured parameters in manure, pond water, initial runoff and runoff after simulated rainfall

Parameter	Units	Dairy Manure	Swine Manure	Pond water
DM initial	% as is	7.4	2.5	0.058
DM runoff	% as is	9.7	9.4	1.3
DM runoff after rain	% as is	0.16	0.11	1.3
TKN initial	% as is	0.30	0.43	0.017
TKN runoff	% as is	0.27	0.38	0.0
TKN runoff after rain	% as is	0.0009	0.003	0.0
P initial	% as is	0.058	0.10	0.005
P runoff	% as is	0.057	0.076	0.0008
P runoff after rain	% as is	0.0003	0.0006	0.0
K initial	% as is	0.22	0.25	0.0
K runoff	% as is	0.22	0.23	0.005
K runoff after rain	% as is	0.004	0.0019	0.0
NH_4-N initial	mg/kg	1240	3230	29
NH_4-N runoff	mg/kg	1360	2880	17
NH_4-N runoff after rain	mg/kg	27	44	21
E. coli runoff after rain	Geometric mean (cfu/100 mL)	5060	2330	118

In 2007, the Dry Matter (DM) contents of the initial runoff were consistently higher than those of the liquids applied. This was not the case in 2008. This suggested that a certain amount of soil or plant material was being carried along with the liquid in 2007. The change in liquid application method was believed to be responsible for at least some of the difference noted here.

Table 10 - 2008 study - Mean values of selected measured parameters in applied liquids and in runoff

Parameter	Units	Dairy Manure	Swine Manure	Pond water
DM initial	% as is	8.5	2.7	0.033
DM runoff	% as is	6.3	1.8	0.40
TKN initial	% as is	0.27	0.20	0.0
TKN runoff	% as is	0.25	0.24	0.0
P initial	% as is	0.058	0.084	0.0
P runoff	% as is	0.050	0.061	0.0
K initial	% as is	0.21	0.090	0.0
K runoff	% as is	0.21	0.14	0.0
NH_4-N initial	mg/kg	1620	1380	0.0
NH_4-N runoff	mg/kg	1460	1870	0.60

Concentrations of TKN, P, K and NH_4-N followed a similar pattern at all sites and in both years. Concentrations of each parameter in the runoff were similar to those in the applied liquids in both years. However, levels of these parameters in the runoff after the simulated rainfall (in 2007) were very low. So many of the samples had concentrations of these parameters near or below the lower detection limit for the test that it was difficult to establish an accurate mean value. It did appear, however, that for the manured plots, the runoff after simulated rainfall was closer in its chemistry to the pond water used in the rainfall simulator than to the initial manure applied to the plots.

In the rainfall simulator study in 2007, microbiological testing was carried out for the runoff sample. The tests confirmed that bacteria present in the manure could run off from the site with a post-application rainfall. While one would expect to see indicator bacteria such as *E. coli* in runoff from manured plots, the fact that *E. coli* was measured in the non-manured plots suggests the impact of background levels in the surface soil. Levels of *E. coli* in the initial manure samples were not measured, but were assumed to be present in densities of at least 1×10^6 cfu/100 mL. The geometric mean density of *E. coli* in the pond water was 21 cfu/100 mL. Soil background levels were not measured. Runoff samples for bacterial analysis were only submitted for Site 07-3. Logistical problems prevented this testing for either of Sites 07-1 or 07-2. For Site 07-3, 17 runoff samples (following simulated rainfall) were submitted for this test.

Other Comments

Part of the initial intention was to make observations outside of the plot area on the **distance** that manure flowed overland after application at the three rates. In 2007, this did not work out as planned, since the tractor typically spread on a plot, then stopped to adjust the speed before proceeding to the next plot. This resulted in a considerable over-application between the plots (with the stopping and starting). This practice generated runoff that was not typical of the rates applied. When the spreader applied manure on a separate piece of land adjacent to the plots, there was virtually no runoff for the few times this took place. Unfortunately, on spreading days, time was at such a premium that it was not possible to do a more thorough job of this part of the study.

The 2008 study setup, varying the setback distances was intended to address this deficiency. However, it still did not look at the maximum distance that manure could travel. Rather, it looked at the relative risks of runoff travelling 50 cm and 100 cm from the edge of the spread area.

As mentioned earlier, the two sites having the steeper slopes in 2008 were planted such that the crop rows ran up the slope. In contrast, in 2007 the two sites with steeper slopes were planted across the slope (the impact appeared to be much less obvious at the sites having the lowest slopes in both years). It appeared that it was easier for runoff to accumulate and travel where it was not impeded by crop rows blocking its path. An example of this is shown in Figure 7.

Summary and Conclusions

Field trials carried out in the late summer of 2007 and 2008 looked at runoff amounts and characteristics, using small plots (1 m wide). This was part of a larger project determining the maximum application rates of liquid manure that are practical (or that should be allowed) on sloping farm land. It also looked into the impact on runoff of rainfall shortly after manure application. Three sites were studied in each year, having average slopes in three general ranges: 2.5 to 3.0%, 4.7 to 6.8% and 9.2 to 15.2%. The sites were chosen in the hopes of representing hydrologic soil group C or D. Texture analysis established that the soils were all silt loam. All were assumed to be in HSG C. Manure was surface-applied onto soils that had received recent tillage and onto un-tilled soils (wheat stubble). In 2007, a tank spreader was used and in 2008, all liquids were applied manually (using buckets). Application rates were 46.7, 93.5 and 140.2 m^3/ha (corresponding to 5000, 10,000 and 15,000 US gal/acre). The main lessons learned from this study:

- There was a considerable amount of variability in runoff from plot to plot, especially at the steeper slopes.
- In 2007, runoff following the initial spreading occurred on 75% of all plots. This number was the same whether the site had been pre-tilled or not. In the 2008 study, there was measureable runoff from 28% of all plots. Part of this decrease can be attributed to the use of setback distances (between spread area and collection trough) on 2/3 of the plots. Part can be accounted for by a more accurate application method that avoided lateral splashing during application. When only the plots with a 0 cm setback are considered (2008 study), 51% of plots generated runoff.
- The volume of runoff increased as the slope increased.
- The volume of runoff from plots receiving liquid swine manure was significantly higher than for dairy manure. DM values in the initial manure were 2.5 to 2.7% for swine manure and 7.4 to 8.5% for dairy. It appeared that manure dry matter was a significant contributor to the risk of runoff at the time of manure application.
- In general, the chemical properties of the collected runoff were similar to those of the applied liquids.
- Concentrations of TKN, NH_4-N, P, K in the runoff liquid following simulated rainfall were much lower than levels in the initial liquids, and better reflected the properties of the simulated rainfall (i.e. pond water).
- When the liquid was applied adjacent to the runoff collection trough, the average runoff volume was greater than when setbacks of 50 cm and 100 cm were used – at the low and medium sloped sites. There was no significant difference for the steepest sloped site (i.e. 08-3). With pre-tillage, no runoff travelled 50 cm from the edge of the applied area - for any of the liquids and at all three rates for Sites 08-1 and 08-2 (average land slopes up to 6.8%).

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