NEAR-SURFACE HYDROLOGY, RUNOFF PRODUCTION, AND SOIL LOSS FROM SURFACE-APPLIED LIQUID SWINE MANURE

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Abstract
Excessive nutrients in surface runoff, especially from manure applications, has been a well-recognized environmental concern. Research in this subject area has been focused on relating surface runoff and soil erosion to nutrient loading with little consideration of physico-chemical conditions of the soil that may affect the chemical transport. In this research, we hypothesized that prolonged saturation may cause a change in soil surface condition, and subsequently, affect runoff and sediment production. A rainfall simulation experiment was conducted on soil pans to examine the effects of liquid swine manure application on runoff and soil loss under different hydrologic conditions. The results showed a significant change in soil loss due to manure application after 7 and 28 days moisture equilibration. A possible explanation for the change in erosion is that the changes in chemical state of the moist soil and their interaction with ions in the manure, especially Na and K, affected soil aggregation and consequently, soil dispersion and loss.

Additional Keywords: aggregate stabilization.

Introduction
Liquid swine manure is largely applied in agricultural lands to improve soil fertility in the United States. Liquid swine manure is an excellent nutrient source containing high rates of potassium (K), sodium (Na), nitrogen (N), phosphorus (P) and other organic and inorganic elements (Choudhary *et al*., 1996). The transport of excessive nutrient in runoff from manure applied fields is a great concern because it can cause eutrophication of lakes and streams NP. Many studies on water quality have been focused on the effects that runoff and soil loss have on the transport of manure compounds (Bhatagar *et al*., 1985; McDowell and Sharpley, 2003). Since manure application can cause changes in the chemical and biological processes at the soil surface, it is conceivable that these bio- and chemical processes may also affect soil aggregation in different moisture conditions, and subsequently affect runoff and soil erosion.

Long-term manure application has been reported as an efficient way to improve soil aggregate stability (Edmeades, 2003). In this research, we are interested in identifying conditions that cause soil to be most sensitive to changes in aggregate stability when liquid manures are applied. We presume the variation in the duration of soil saturation would cause a change in the chemical and biological equilibrium, which in turn affects the soil dispersion and aggregation. The objectives of this research are to identify soil conditions wherein manure application may cause a change in soil aggregate stability and erodibility as well as the controlling chemical and biological processes that cause the changes in soil aggregate stability. Results should provide information to understand the bio- and chemical effects of manures on soil erodibility and to develop a proper manure application strategy to minimize its environmental effects.

Materials and Methods
The surface horizon (ie. 0-10 cm depth) of a Toronto silty clay loam soil (Udollic Epiaqualfs) was collected from Purdue University Animal Research Farm, air-dried, sieved through an 11 mm sieve and stored in large containers. Eleven runoff boxes (45 cm long, 31 cm wide and 35 cm deep) were packed with an 11 cm layer of gravel and a 5 cm layer of sand over the gravel before being overlain with 20 cm of sieved soil. After the preparation of the runoff boxes, a pre-wetting rain of 12 mm h^{-1} was applied for 1 h. The soil boxes were saturated from the bottom and allowed to equilibrate for either a single night, or over 7 or 28 days (ie. 1, 7 and 28 day treatments).

Six treatments consisting of 3 hydrologic treatments (ie. 1, 7 and 28 day saturation) and two manure treatments (manure applied and control with no manure), were applied with two replicates each. One replication of the 28 day manure applied box was lost during the rainfall run. 950 mL of liquid swine manure collected from the Purdue Animal Research Farm was sprayed uniformly onto the the surface of each treatment after the designated equilibrium period (ie. 1, 7 or 28 days) and one hour prior to the simulated rainstorm. A simulated rainstorm of 63 mm h^{-1} was applied for 1 h and runoff samples were collected in 1 L bottles at 3 min intervals. Immediately after sample collection, the runoff bottles were weighed, oven-dried for 24 h at 110^{o}C and weighed again. The runoff and sediment discharge were calculated from the wet, dry and tare weights of the runoff bottle. To measure soil redox potential, four platinum electrodes were inserted into the soil box with two electrodes at 2 cm and two at 10 cm depth. The soil redox was measured daily.

Results and Discussion

Chemical properties of the soil and manure are shown in Table 1. The soil is dominated by clay illite, smectite and kaolinite, which are commonly minerals found in soils of the Midwest region of the United States. Figure 1 shows the average runoff from the eight treatments. The runoff volumes are not significantly different among the six treatments despite a slightly increasing trend with aging for the 7 and 28 day equilibrium.

Table 1. Soil and manure properties.

	K ppm	Na ppm	Mg ppm	Ca ppm	Fe ppm	NO3-N ppm	Exch. Al ppm	Org. matter (%)	C:N Ratio	CEC (cmol. kg^{-1})	pH
Soil	264	14	650	2200	49	122	2	4.1	11.5	56.7	6.1
Manure	647	321	29	83	2.5	123	6	<0.19	7.6	-	7.4

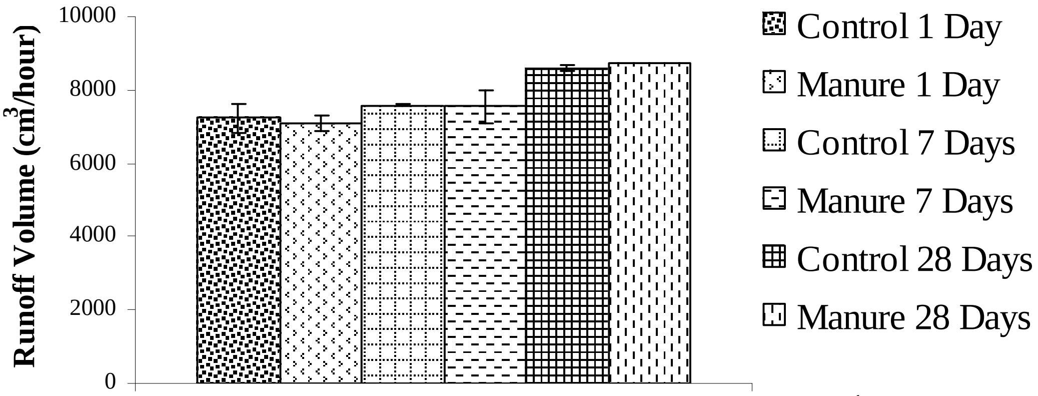

Figure 1. Total runoff volume from a simulated rainstorm of 63 mm hr^{-1} for 1 hour.

The average soil loss is shown in Figure 2. Without manure application, the soil losses from different saturation times were not significantly different. The application of liquid swine manure increased the total soil losses from the 7 and 28 day equilibrium treatments when compared to the control (no manure). The 1 day treatment with manure applied showed the lowest rate of soil loss indicating a possible physical sealing effect (Figure 2).

The redox potential (Eh) decreased rapidly during the first 7 days of saturation and remained almost constant afterwards (Figure 3). The electrode readings at 10 cm depth indicate a more strongly reduced state.

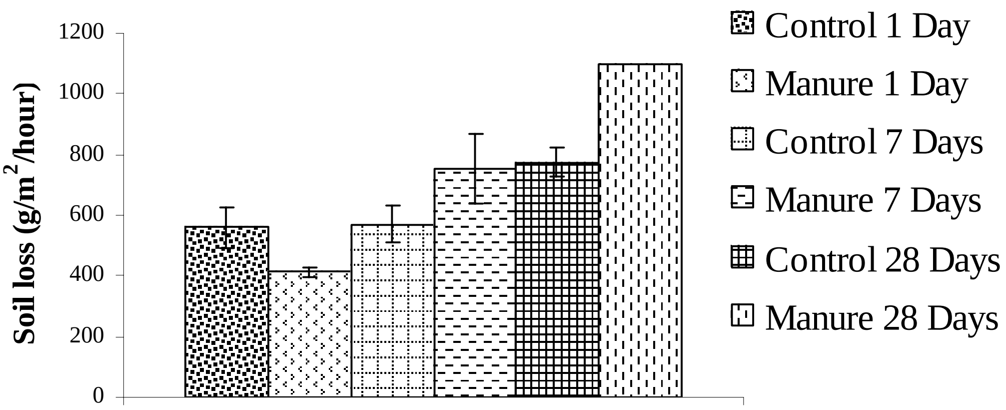

Figure 2. Total soil loss from a simulated rainstorm of 63 mm hr^{-1} for 1 hour.

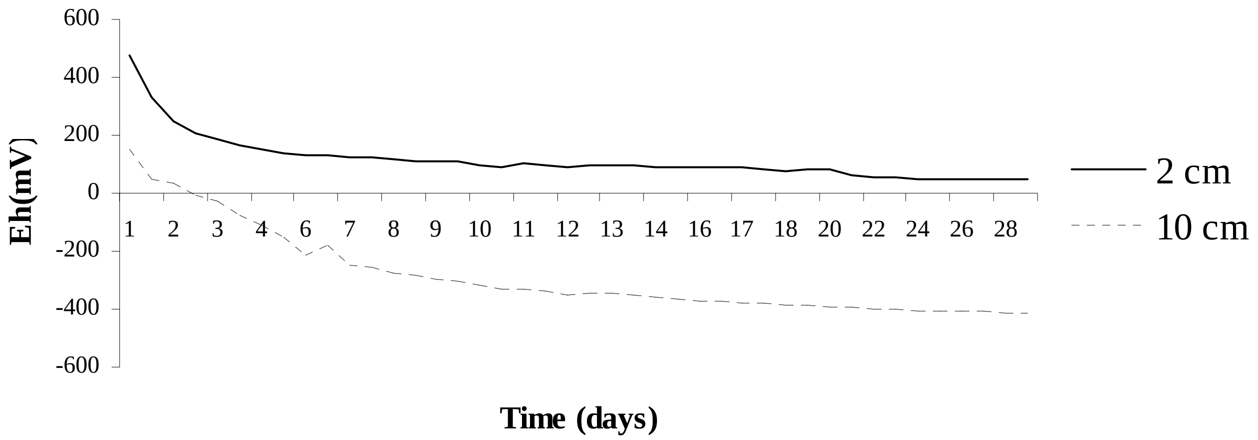

Figure 3. Average redox potential at 2 cm and 10 cm depth from all replicates.

Runoff volumes increased slightly under the prolonged saturation however the increase is significantly less than the soil loss. Saturation of the control (no manure) soil for 7 and 28 days may have caused changes in the physical and chemical states of the soil, but these changes did not affect the net soil loss. Changes in inorganic stabilizers as well as clay swelling have been reported as factors affecting aggregate stabilization (Amezketa, 1999). Under prolonged wet conditions (ie. 7 and 28 days), the reduced state may cause changes in the soil inorganic aggregate stabilizers, such as Fe^{3+} and Ca^{2+}, therefore decreasing the aggregate stabilization. Saturation also facilitates aggregate stabilization and increased soil loss.

Changes in soil erosion from adding liquid swine manure one hour before the rainfall event is probably attributed to chemical processes because of the quick response. The soil from 7 and 28 day saturation with manure applied was destabilized causing greater soil dispersion. Dispersion largely an electrostatic phenomenon (Tisdall and Oades, 1982) is enhanced by saturation and the monovalent cations. The liquid swine manure has high concentrations of Na and K and these cations clay dispersants (Auerswald *et al*., 1996). Under prolonged wet conditions, the manure cations, such as Na and K, possibly interacted quickly with the negatively charged sites of minerals, organic matter or colloids, causing an increase in the soil dispersion and consequently in the soil loss. Sodium in particular has been reported as an effective agent in decreasing wet aggregate stability (Cameron *et al*., 2003). The application of liquid swine manure with slightly alkaline conditions (pH 7.4) on a wet soil may raise the soil solution pH causing an increased net negative charge of clays thus favouring clay dispersion by enhancing the interlayer repulsive forces and swelling.

The physical effects of sealing shown from the results of 1 day manure treatment may be related to both the interaction of manure application and the soil moisture condition. It may be that the soil saturation for the 1 day treatment was not sufficient to reach full clay expansion near the surface and therefore, the manure to bind more tightly with the clay minerals instead of diffusing into the wet soil.

Conclusions

Soil aggregate stability can be affected by time of saturation and the reduction condition it created. Under the prolonged wet condition, the reduction processes dominate and cause a change in aggregate stabilizers and a net decrease in aggregate stability. Elevated levels of monovalent cations in the liquid manure may have triggered soil dispersion. Therefore, application of liquid swine manure should be avoided in wet soils in order to minimize aggregate destabilization and soil loss.

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