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Tillage system and time post-liquid dairy manure: Effects on runoff, sediment and nutrients losses

Verediana Fernanda Cherobim[a], Chi-Hua Huang[b], Nerilde Favaretto[a,*]

[a] DSEA-UFPR, Department of Soil Science and Agricultural Engineering, Federal University of Paraná, Curitiba, Paraná, Brazil
[b] USDA-ARS National Soil Erosion Research Laboratory, Brazil

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ABSTRACT

Liquid manure applied in agricultural lands improves soil quality. However, incorrect management of manure may cause environmental problems due to sediments and nutrients losses associated to runoff. The aims of this work were to: (i) evaluate the time effect of post-liquid dairy manure (LDM) application on runoff, sediment and nutrient losses; (ii) compare the effect of conventional tillage and no-till systems on runoff, sediment and nutrients losses after LDM application. A rainfall simulation experiment was conducted on intact soil blocks collected from fields that had been under conventional tillage and no-till systems. Rainfall was applied 24 h or 7 days after LDM application. Conventional tillage without manure application resulted on higher runoff, sediment and nutrient losses (mainly the particulate fraction) than no-till without manure. The greatest runoff, sediment and nutrients losses occurred in the treatments where simulated rainfall was performed 24 h after LDM application independent of the tillage system. An interval of 7 days between manure application and the rainfall event reduced sediment, particulate P, and particulate N losses in both conventional and no-till systems. In practical terms, we would recommend a minimum of 7 days between LDM application and rainfall-runoff event to provide agronomic benefits minimizing the potential risk of water pollution.

1. Introduction

Liquid manures are commonly used in agricultural soils as effective sources of plant nutrients, as well as their potential to improve the chemical, physical, and biological properties (Adeli et al., 2008; Fares et al., 2008; Kheyrodin and Antoun, 2011). However, inappropriate management of manure, such as application methods, excessive rates and timing of application may cause negative effects on water quality (Allen and Mallarino, 2008; Kaiser et al., 2009; Lord, 1996).

Manure applied on soil surface is extremely vulnerable to nutrient losses as surface runoff into ditches and streams, especially when rainfall occurs shortly after application (Allen and Mallarino, 2008; Mori et al., 2009; Tabbara, 2003).

Phosphorus and nitrogen are essential for plant growth, but their application in agricultural fields should be carefully managed, because improper management may result in surface and subsurface water pollution (Casalí et al., 2008; Kato et al., 2009; Wang et al., 2016). Manure application without incorporating into the soil promotes stratification of P within the topsoil with high concentration of P at the soil surface and low potential for P sorption to the soil (Schwab et al., 2006; Sharpley, 2003). In no-till soils, the build-up of nutrients at the surface increases the potential for P and N loading to runoff water, especially in dissolved forms (Sharpley, 2003; Smith et al., 2007).

The transport of nutrients from soil to water may be as soluble or adsorbed to soil particles (mineral and/or organic). Phosphorus transport is mainly associated to surface runoff and nitrogen to leaching (Hatch et al., 2002; Leinweber et al., 2002; Sharpley et al., 1987). For NO_3-N, due to the low retention capacity in most soils, leaching is the main process involved in transporting of this ion from soil to water (Eghball and Gilley, 1999). However, precipitation events soon after the application of fertilizers (mineral or organic) can promotes losses of N-NO_3 in surface runoff (Bertol et al., 2005; Hatch et al., 2002), although its losses are generally small. On the other hand, nitrogen as NH_4-N and particulate N may represent significant losses via surface runoff (Hooda et al., 2000). Due to the high sorption capacity, particulate P (P bounded to the sediment), generally, dominates P loss by surface runoff on conventional agricultural systems (Kleinman et al., 2011; Verbree et al.,

* Corresponding author at: Departamento de Solos e Engenharia Agricola, Universidade Federal do Paraná, Rua dos Funcionários 1540, 80035-050 Curitiba, Paraná, Brazil.
E-mail address: nfavaretto@ufpr.br (N. Favaretto).

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2010). Therefore, controlling the sediment loss as been considered as an effective way to reduce the nutrients loss. Management practices such as conservation tillage systems are effective in reducing soil erosion, and consequently, nutrient losses adsorbed to the sediment (particulate form) and Total N and Total P in surface runoff (Bortolozo et al., 2015; Ramos et al., 2014; Sharpley et al., 2013; Sharpley and Wang, 2014).

The interval between manure application and the rainfall-runoff event have been shown to be an important factor affecting losses of water, sediment and nutrients. In a field experiment with no-tillage, liquid manure applied on soil surface reduced water infiltration 24 h after application (Cherobim et al., 2015). The lower infiltration and consequently higher runoff was possible due to the surface sealing as a result of clogging of pores (Barrington et al., 1987; Culley and Phillips, 1982). Studies show that when a rainfall event occur immediately after manure application, the P and N concentrations in runoff are greater than when the first rainfall occur in few days after application (Allen and Mallarino, 2008; Schroeder et al., 2004; Smith et al., 2007; Tabbara, 2003). Extending the timing between a rainfall-runoff event and manure application can significantly reduce the risk of excessive runoff nutrients concentration (Hanrahan et al., 2009). In this study, we are particularly interested in how the timing of the rainfall event affects sediment and nutrient runoff after surface application of liquid manure under different tillage systems.

A laboratory rainfall simulation experiment with undisturbed soil sample was designed to: (i) evaluate the interval time effect after application of liquid dairy manure (LDM) on the water, sediment and nutrient losses; and (ii) compare the effect of LDM application in conventional tillage and no-till systems on water, sediment and nutrients losses. This study will provide recommendations of management practices on LDM that offer agronomic benefits with minimal potential risk of water pollution.

2. Material and methods

2.1. Experimental site and treatments

This study was performed in the USDA-ARS-National Soil Erosion Research Laboratory at West Lafayette, Indiana. Undisturbed soil samples were collected from the 0 to 0.1 m layer in conventional tillage (CT) and no-till (NT) fields at the Throckmorton Purdue Agricultural Center (TPAC) in Lafayette, Indiana. The study soil was an Alfisol Miami silt loam (USDA-Soil Survey Staff, 1999). A detailed description of chemical and physical soil characteristics is shown in Table 1. The soil samples were collected in September/October 2014, using metal boxes with the dimension of 0.45 × 0.30 × 0.10 m. The crop residues present on the soil surface were not removed, however the amount of crop residue was minimal.

The experiment consisted of six treatments with three replicates: two tillage systems (CT and NT), two intervals between manure application and rainfall simulation, i.e., 24 h and 7 days, and the control (CT and NT without DLM application). The liquid dairy manure (Table 2) at dosage of 60 m^3 ha^{-1} was manually applied on the soil surface and the rainfall simulation was performed 24 h (24 h) and seven days (7days) post-manure application.

Table 2
Liquid dairy manure (LDM) characterization.

	pH	Total dry solids	TKN	NH_4-N	TP	K	Ca	Mg	Na
		%	mg L^{-1}						
LDM	7.5	3.5	2180	1430	360	1270	1300	603	596

TKN, Total Kjeldahl Nitrogen; NH_4-N, Ammonium Nitrogen; TP, Total Phosphorus; K, Potassium; Ca, Calcium; Mg, Magnesium; Na, Sodium.

The treatments were defined as: CT control and NT control (no manure added), CT 24 h and NT 24 h (rainfall simulation 24 h after LDM application), CT 7 days and NT 7 days (rainfall simulation 7 days after LDM application).

2.2. Simulated rainfall and runoff samplings

Simulated rainfall was applied using deionized water at an intensity of 50 mm h^{-1} for 60 min. The soil sample was set to 10% slope. Prior to each simulation, a pre-wetting low intensity rain of 12 mm h^{-1} was applied for one hour and the soil samples were equilibrated for 24 h. This procedure minimized the differences between the antecedent soil water conditions among the treatments and resulted in all the soil samples near their field capacity before the 50 mm h^{-1} runoff-generating rainstorm. The time between rainfall and runoff start was around 3 min for all treatments (with or without liquid manure application).

During the 60 min rainfall event, samples were collected every 5 min after runoff initiation. The runoff sample for sediment data was taken in a tared one-liter bottle for two minutes. Immediately after the sediment sample collection, additional runoff samples were taken for soluble and total nutrient analyses. Sediment runoff samples were weighed and then dried at 105°C. Runoff amounts and sediment concentrations were determined gravimetrically. For nutrient analyses, a sample of 60 mL was collected for total digestion (unfiltered samples), while a sample of 20 mL was filtered using 0.45 μm syringe filters to analysis soluble nutrients. Filtered and unfiltered samples were acidified with concentrated sulfuric acid to pH < 2 and were frozen to further chemical analysis.

To determine nutrient concentrations in the runoff samples, colorimetric analyses were conducted on a Thermo Scientific KoneLab 20 water chemistry auto-analyzer. Dissolved reactive phosphorus (DRP), nitrate (NO_3-N) and ammonium (NH_4-N) were analyzed with EPA method 365.2, EPA method 353.1 and EPA method 350.1, respectively (U.S. EPA, 1979). Unfiltered water samples were digested with mercuric sulfate and then analyzed total Kjeldahl nitrogen (TKN) and total phosphorus (TP) with test method based on EPA method 351.2 rev 2 (O'Dell, 1993) and EPA method 365.4 (U.S. EPA, 1979). Particulate phosphorus (PP) was obtained by subtracting DRP from TP and particulate nitrogen (PN) was obtained

Table 1
Soil characterization.

Tillage system		Physical properties					Chemical properties						
	Depth	Sand	Silt	Clay	MWD	ρ_s	Ca^{+2}	Mg^{+2}	K^+	P Mehlich	NO_3-N	pH	OC
	m	g kg^{-1}			mm	g cm^{-3}	mg kg^{-1}						g kg^{-1}
CT	0–0.05	440	420	140	0.13	1.33	1522	302	296	140	19	6.4	14.5
CT	0.05–0.10	460	380	160	0.14	1.44	1572	317	218	80	22	6.5	12.8
NT	0–0.05	440	480	80	0.50	1.21	1974	300	422	122	5	6.8	23.8
NT	0.05–0.10	400	460	140	0.46	1.29	1670	321	265	94	6	5.9	13.9

CT: Conventional Tillage; NT: No-till; MWD: Mean Weight Diameter (wet); $\rho_{s:}$ bulk density; NO_3-N: Nitrate Nitrogen; OC: Organic Carbon.