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Water infiltration post-liquid dairy manure application in no-till Oxisol of Southern Brazil

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ABSTRACT

Use of liquid dairy manure (LDM) is a common practice by livestock producers. However, soil, water and nutrient losses occur after intense rainfall. The objectives of this study were to: i) verify which infiltration model, i.e., Kostiakov–Lewis, Horton or Philip, is more appropriate to estimate final infiltration rate in a no-till soil after different amounts of LDM application (0, 30, 60 and 90 $m^3 ha^{-1}$); and ii) evaluate the effect of LDM application on the infiltration rate over time (1, 5, 10, 25 and 40 days). LDM application resulted in high infiltration variability. Among the infiltration models, the Horton model retained the best fit. The lowest final infiltration occurred at 90 $m^3 ha^{-1}$, 1 day post LDM application. Overall, infiltration did not differ for any LDM dosage for intervals longer than 5 days. Based on our analysis, we would recommend a maximum LDM dosage of 60 $m^3 ha^{-1}$ applied at least 5 days prior to high intensity rainfall. This procedure would minimize environmental problems with runoff associated pollutants.

1. Introduction

Storage and disposal of animal waste is a worldwide challenge (Chadwick and Chen, 2002). Land application of solid or liquid manures from animal productions represents a sustainable management practice and provides an opportune method for recycling nutrients as well as returning organic matter to soil (Choudhary et al., 1996). Physical and hydraulic soil properties, such as porosity, bulk density, water-stable aggregates, saturated hydraulic conductivity and water infiltration were improved with long-term manure application (Fares et al., 2008; Mellek et al., 2010; Yagüe et al., 2012). Soil chemical and biological properties, such as organic matter, nutrients (P, Ca, Mg and Zn) levels (Adeli et al., 2008; Kheyrodin and Antoun, 2011), microbial diversity activity and decomposers activity (Ndaaegamiye and Côté, 1989; Van Eekeren et al., 2009) also increased with manure application. Improvement in soil quality leads to an increase in crop productivity (Bandyopadhyay et al., 2010). However, inappropriate timing of manure application may have negative effects, such as soil, water and nutrient losses, especially when applied prior to of high intensity rainfall (Allen and Mallarino, 2008; Mori et al., 2009). Therefore, management practices to mitigate runoff-associated pollutants should be implemented in order to reduce its water quality impacts (Shigaki et al., 2006).

Soil crust (a layer characterized by greater density and lower porosity) is common in unprotected soil surface under high intensity rainfall (Hillel, 1980; Sumner and Stewart, 1992). Use of animal slurry can also promote soil surface sealing through physical mechanism by clogging of pores due to the total solid content, i.e., dry matter (Barrington et al., 1987) and chemical mechanisms through clay dispersion by ions, such as sodium (Cihan et al., 2006). It has been shown that the soil surface seal formed by liquid manure application reduced water infiltration, thereby increased the volume and velocity of runoff (Barrington et al., 1987; Culley and Phillips, 1982). Therefore, the rate of infiltration is influenced by the solid content of any material applied, i.e., a higher total solid content would result in a lower infiltration rate (Thomas et al., 1966). Infiltration can also be reduced due to hydrophobic compounds present in the manure, which act to repel water (González-Peñaloza et al., 2012).

It is generally accepted that long-term application of manure, either incorporated or surface applied, decreases runoff (Gilley and Risse, 2000) and increases water infiltration by improving soil physical properties such as macroporosity and aggregate stability (Mellek et al., 2010; Rasoulzadeh and Yaghoubi, 2010). However, rainfall shortly after application of liquid manure caused an

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Table 1
Chemical properties of the soil investigated.

Depth m	pH $CaCl_2$	Al^{3+}	$H^+ + Al^{3+}$	Ca^{+2}	Mg^{+2}	K^+	*P* mg dm^{-3}	*C* g dm^{-3}
		----------$cmol_c dm^{-3}$----------						
0–0.05	5.3	0	5.0	8.4	4.4	0.5	12.7	19.2
0.05–0.10	5.7	0	4.0	6.9	4.4	0.3	5.7	21.2
0.10–0.20	5.8	0	3.4	6.5	4.2	0.2	3.6	23.2

increase in surface runoff (Allen and Mallarino, 2008; Mori et al., 2009) due to reduced infiltration (Roberts and Clanton, 2000). Thus, it is expected that a longer time interval between liquid manure application and high intensity rainfall event may result in higher infiltration (Gilley et al., 2007) considering the short-term effect of soil surface sealing by manure on infiltration and runoff may diminish (Bundy et al., 2001).

Infiltration is one of the most important processes when studying the movement of water in soil (Jury et al., 1991; Hillel, 1998) and it can be modeled by different methods. Considering the difficulty and time expenditure of the in situ method (Haghighi et al., 2010) several models have been developed to estimate the infiltration rate, for example Kostiakov–Lewis, Horton, Philip, among others (Jury et al., 1991).

The aims of this work were to: (i) verify which infiltration model (Kostiakov–Lewis, Horton or Philip) is more appropriated to estimate final infiltration rate (i_f) in a clay rich, no-till soil after liquid dairy manure application; (ii) evaluate the time effect of LDM on the infiltration rate following manure application. This study will provide a practical recommendation for the use LDM and a dataset to show the risk of manure runoff potential after LDM application.

2. Materials and methods

2.1. Experimental area

This study was carried out in a research station of the Foundation for Agricultural Assistance and Technical Divulgation situated near the town of Castro, Campos Gerais region, Parana State, Brazil (24°51′50″S and 49°56′25″E). Experiments were conducted in a soil classified as Oxisol (USDA soil taxonomy) with clayed texture (60% clay) in the 0-0.20 m layer (Tables 1 and 2), 7% slope and managed with no-tillage over the past 20 years. The regional climate is classified as Cfb – Humid subtropical climate mesothermal (Köppen), with mild summers and average annual rainfall of 1554 mm, without a dry season (Caviglione et al., 2000). During the experimental period (40 days), accumulated rainfall was 185 mm and the average maximum temperature, minimum temperature, speed wind, solar radiation and soil water content were 20.2 °C, 11.8 °C, 2.2 m s^{-1}, 1.1 W m^{-2} and 24.5%, respectively (Table 3).

2.2. Chemical and physical characterization of soil

Chemical (Table 1) and physical (Table 2) properties of the soil were measured at depths of 0–0.05, 0.05–0.10 and 0.10–0.20 m. Chemical analyses, i.e., pH $CaCl_2$, C, exchangeable Ca, Mg, K, P, and Al, were performed in air-dried soil samples, sieved through a 2 mm sieve according to Pavan et al. (1992). For the texture analysis, particle size distribution was measured in disturbed soil samples by densimeter (Bouyoucos, 1962). For aggregate stability, soil samples were passed through an 8 mm mesh, air dried and separated into fractions using 4, 2, 1, 0.50 and 0.25 mm mesh by dry (mean weight diameter of dry aggregates; MWDdry) and wet (mean weight diameter of wet aggregates; MWDwet) sieving (Kemper and Rosenau, 1986). For saturated hydraulic conductivity (K_s), soil bulk density (ρ_s) and total porosity (α), undisturbed samples (74 cm^3) were collected using volumetric rings (height 3 cm; diameter 5.6 cm). Particle density (ρ_p) was determined with volumetric flasks using ethanol method (Blake and Hartge, 1986). Microporosity was measured at the end of a 24-h period under 6 kPa. Macroporosity was obtained from the difference between total porosity and microporosity. Total porosity was calculated according to Danielson and Sutherland (1986). The saturated hydraulic conductivity was measured by the constant head method (Klute and Dirksen, 1986).

2.3. Treatments

LDM treatments (three replicates) were performed at four different dosages (0, 30, 60 and 90 m^3 ha^{-1}) with five intervals between manure application and analysis of infiltration (1, 5, 10,

Table 2
Physical properties of the soil investigated.

Depth m	Clay	Silt	Sand	MWD_{dry}	MWD_{wet}	ρ_s kg m^{-3}	Mac	Mic	α	K_s mm h^{-1}
	----g kg^{-1}----			----mm----			-----%----			
0.0–0.05	550	272	178	2.55	2.11	1100	11.8	47.2	59.0	84.3
0.05–0.10	600	202	198	2.79	2.38	1220	9.1	45.0	54.1	12.4
0.10–0.20	610	208	192	2.44	1.91	1200	7.8	47.0	54.8	10.4

MWD_{dry}: mean weight diameter of dry aggregates; MWD_{wet}: mean weight diameter of wet aggregates; ρ_s: soil bulk density; Mac: macroporosity; Mic: microporosity; α: total porosity; K_s: saturated hydraulic conductivity.

Table 3
Rainfall, temperature, solar radiation, wind speed and soil water content during the study.

Days post LDM application	Rainfall	Temperature (C°)		Solar radiation	Wind speed	Soil water content at 0–0.1 m
	mm[a]	max	min	W m^{-2}	m s^{-1}	%
1	1.0	24.7	16.9	11.1	1.9	24
5	0.0	22.3	14.7	15.1	2.7	26
10	15	21.9	13.3	8.2	1.1	21
25	0.0	21.2	11.4	13.2	1.5	27
40	1.2	19.5	11.4	10.8	1.9	25
Average		20.2	11.8	11.1	2.2	24.5

[a] Rainfall volume one day before the infiltration test, but the experimental plots were covered by plastic canvas during the experimental period to avoid rainfall effect. The accumulated rainfall during the experimental period (40 days) was 185 mm.