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

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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.,

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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.

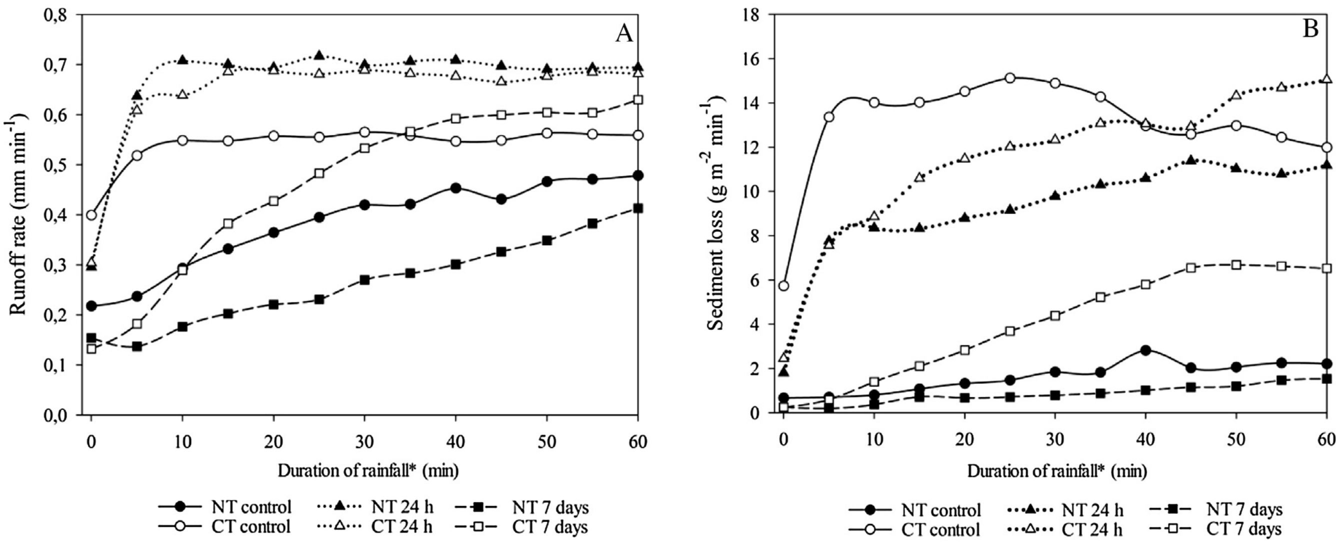

Fig. 1. Runoff rate (A) and sediment loss (B) under a single rainfall (~50 mm h^{-1}) for 1 h in conventional tillage (CT) and no-till (NT) and time post-manure application (24 h and 7days).

by subtracting N-NH_4 from TKN. Total nitrogen (TN) was calculated by the sum between TKN and N-NO_3.

2.3. Statistical analysis

Analysis of variance and Tukey's test ($P < 0.05$) for mean comparisons procedures and Pearson correlation analyses ($p < 0.05$) were performed using the STATISTICA 10 software (StatSoft, 2011).

3. Results and discussion

3.1. Runoff rate and sediment loss

Fig. 1 shows the runoff and sediment discharge during the 60-min simulated rainfall. The runoff rate during the simulated rainfall had similar behavior for CT control, CT 24 h and NT 24 h treatments. The runoff rate was lower in the beginning of the rain and after 5 min, it remained constant (Fig. 1A). This probably was due to surface sealing and clogging of pores from the LDM application (Barrington et al., 1987; Culley and Phillips, 1982) in the CT 24 h and NT 24 treatments; or by the raindrop splash (Bradford and Huang, 1994) in the CT treatments. For NT control, NT 7 days and CT 7days, the runoff increased gradually (Fig. 1A). For NT control treatment, lesser runoff than CT control can be explained by the higher soil aggregation and stability (Table 1), which promoted greater infiltration. For treatment CT 7days, the dried manure possibly provided soil surface protection against raindrop impact (Barthès et al., 1999), and therefore, increased water infiltration. The lower runoff rate in the NT 7 days probably occurred due to the greater soil aggregation (Table 1) as the protection against raindrop impact by the crust formed with the dried liquid manure (Barthès et al., 1999).

The total runoff for the 60 min rain interval was higher for the CT 24 h and NT 24 h treatments (~42 mm h^{-1}) and lower for the NT 7 days (~17 mm h^{-1}). Comparing the control and manured treatments, we observed that for conventional tillage the runoff increased 20% in CT 24 h and reduced 14% in CT 7days, while for no-till the runoff rate increased 72% in NT 24 h and reduced 32% in NT 7 days (Table 3). Time interval between LDM application and rainfall event resulted in a significant effect on cumulative runoff loss. The treatment of 7 days after LDM application compared to 24 h treatment reduced runoff loss on average 26% and 60% to conventional tillage and no-till, respectively. This runoff reduction in 7 days after LDM application reinforces the idea of the dried manure promoting soil surface protection against raindrop impact (Barthès et al., 1999), influencing on soil water infiltration. Cherobim et al. (2015) in a study with no-till system, noted that the LDM application on the soil surface influenced the water infiltration mainly in the first five days, after that the infiltration rate was not different among treatments.

The sediment loss during the rainfall event (Fig. 1B) followed the runoff loss pattern (Fig. 1A). Three treatments, i.e., CT control, CT 24 h and NT 24 h showed significantly greater sediment losses during the 1-h rain, with the CT control treatment showing the greatest loss in the first few minutes. In conventional tillage, the higher losses occurred due the soil disaggregation (Meijer et al., 2013) that facilitated the particles transport through the runoff.

Regarding the cumulative sediment loss, CT control, NT 24 h and CT 24 h showed greater losses and these losses were not statistically different, while NT control and NT 7 days showed less sediment losses (Table 3). Comparing CT treatments, a delay of 7 days after the manure application before the rain event caused a significant reduction in the sediment loss (~850 and ~263 g m^{-2} h^{-1}, respectively) around 70%. This result reinforces the idea of the possible action of the manure on soil protection against disaggregation by rain drop, especially for conventional tillage.

When comparing tillage systems, our results clearly demonstrate that CT caused higher sediment loss than the NT system, reinforcing that tillage is the major factor driving the sediment loss in the runoff process (Beniston et al., 2015). The conservative tillage system, such as no-till, improves soil stabilization, water infiltration and water holding capacity (Cruse and Herndl, 2009; Sharpley and Wang, 2014), increases soil organic matter in the topsoil (Lal, 2003) and decreases the export of sediment in runoff water (Tiessen et al., 2010).

3.2. Nutrients loss

3.2.1. Phosphorus

The losses of different phosphorus fractions are presented in Fig. 2A, C and E, and these losses are directly associated with their concentrations (Fig. 2B, D, F). The results for TP and PP in the conventional tillage were similar. Treatment CT 24 h showed high TP and PP losses in the first 30 min, then decreasing gradually. These losses are related to the concentrations of P bound to sediments.

Table 3
Cumulative losses of runoff and sediment for different tillage system and time post-manure application.

	CT Control	CT 24 h	CT 7 days	NT Control	NT 24 h	NT 7 days
Runoff (mm)[a]	35 ab	42 a	30 b	25 bc	43 a	17 c
Sediment ($g\,m^{-2}$)[a]	844.5 a	741.7 a	262.9 bc	105.3 c	595.7 ab	54.7 c

CT: Conventional tillage; NT: No-till; Control: treatment without LDM application; 24-h: treatment with LDM and simulated rainfall 24 h after LDM application; 7-days: treatment with LDM and simulated rainfall 7 days after LDM application.

[a] Means followed by the same letter are not significantly different by Tukey's test ($P < 0.05$).

Losses of DRP the treatments CT 24 h and NT 24 h were also high in the beginning, and decreasing gradually (Fig. 2E). This phenomenon was caused by the high concentration of soluble P present in the LDM that results in greater P losses mainly in the first minutes of runoff. For other treatments, the losses of all forms of P were mostly constant during the rainfall event (Fig. 2A and B).

For cumulative P losses from the 1-h rain event, the total P was the highest in CT 24 h (1527 $mg\,m^{-2}$), followed by NT 24 h (834 $mg\,m^{-2}$). The high TP loss in the CT 24 h is due to high PP loss. For CT 24 h, the TP loss was 336% greater than that from the CT control, whereas TP loss from NT 24 h was 916% greater as compared to NT control. Seven days after the manure application, TP from the CT 7 days decreased by 80% as compared to the TP loss from CT 24 h, while NT 7 days decreased 88% as compared to NT 24 h (Table 4). Comparing the control treatments in the partition of the P fractions, the percentage of TP as DRP was higher in the no-till than in the conventional tillage (i.e., 7.3% vs. 0.8%), while PP showed the inverse proportion (Table 5). However, in terms of cumulative losses, the conventional tillage lost 45% less to DRP and 180% more to PP, when compared to the no-till treatment (Table 4).

The loss of particulate P was higher in 24 h after manure application in both tillage systems. This occurred probably because the liquid manure recently applied in the surface had light organic matter that floated and was transported in the runoff (Mcdowell and Sharpley, 2002). After 7 days, the drying and crusting of manure decreased the availability of light organic matter to runoff and decreased the PP loss (Kleinman and Sharpley, 2003; Vadas et al., 2007). Due the lower aggregate stability, the CT treatment had greater loss of organic materials from LDM plus soil particles than those from the NT treatment.

The absence of a significant difference in total P loss between NT control and NT 7 days and between CT control and CT 7 days can be related to sediment loss, soil-bound P, and desorption of Johnson et al. (2011), working with dairy manure slurry in a no-till system and applying simulated rainfall 72 h post application, did not find differences in total P loss when compared control treatment and treatment with slurry applied in the soil surface.

In our study, the highest DRP loss occurred in the treatments with rainfall simulation 24 h following LDM application, in both no-till and conventional tillage system (Table 4). Johnson et al. (2011) also observed highest DRP loss in manured treatments when compared to control treatment (no manure). In the treatments with 7 days post LDM application, the DRP loss decreased, however the loss remained greater that control treatments in both systems, demonstrating similar tends are those observed by Vadas et al. (2007). Time interval between rainfall event and LDM application had a significant effect on DRP concentration and loss (Table 4). A rainfall event occurring 7 days after liquid manure application reduced DRP concentration and loss on average 70% and 76% to conventional tillage, and 78% and 91% to no-till, respectively.

The time interval between manure application and runoff event has an essential role in the P losses. Avoiding manure application before a forecasted rainfall event is very important to minimize P losses (Schroeder et al., 2004; Allen and Mallarino, 2008). Moreover, it is worth emphasizing that the applied manures can contribute as dissolved P in runoff for a long time after they are applied on soil (Vadas et al., 2007).

3.2.2. Nitrogen

The losses of total N, particulate N, NO_3-N, and NH_4-N are shown in Fig. 3A, C, E and G, respectively, with the concentration data following similar trends as the mass loss (Fig. 3B, D, F and H). Total N, particulate N and NH_4-N had the same behavior, showing greatest losses occurred from the 24 h treatment of both CT and NT systems, mainly during the first few minutes of the applied rainfall. The NO_3-N loss from the NT 7 days treatment show highest losses among all treatments during the one hour rainfall event, but the amounts were very small. The CT and NT control treatments behaved similarly, showing lowest losses among all treatments independent of N-fractions. For total N, the treatment of 7 days after LDM application reduced the loss in both tillage systems. This occurred mainly due to the decreased concentration of particulate N in relation to 24 h post-application treatment.

For cumulative nitrogen losses (Table 4), the total N (TN) and particulate N (PN) losses were higher in the NT 24 h and CT 24 h treatments. The cumulative losses of TN and PN for NT control and NT 7 days were significantly lower than others treatments. Increasing time between LDM application and rainfall event decreased the loss of NH_4-N, PN and TN, corroborating the results by Smith et al. (2007). Comparing cumulative loss of NH_4-N in 24 h versus 7 days treatments, the loss was decreased 87% in CT and 96% in NT treatments.

The cumulative loss for nitrate was higher in LDM treatments when compared to control treatments. In contrast to NT, PN and NH_4-N concentrations, NO_3-N concentrations (Table 4) increased as time increased. The cumulative loss of NO_3-N was higher in 7 days after LDM application, this probably occurred by the nitrification process (nitrifying bacteria). It is common for greater biological activities in no-till soils than in conventional tilled soils, which can explain the greater losses in no-till system (Table 4). Sharpley and Wang (2014) showed that conservative tillage caused an increase in nitrate and soluble P losses.

Among all the treatments, the biggest fraction of N concentration was as particulate N (>70%). In the control treatments, the particulate fraction was even higher, i.e., 99.5 and 95.8% in CT and NT, respectively (Table 5). It is common to have a strong correlation between the loss of particulate nutrients and sediment loss (Kleinman et al., 2011; Vadas et al., 2007). In our experiment, the PN concentration was positively correlated to sediment loss ($r = 0.73$).

4. Conclusion

Runoff, sediment and nutrient losses (mainly the particulate fraction) were affected by tillage systems. Without the manure application, conventional tillage resulted in higher losses than those from no-till system. The greatest fractions of nutrient losses were found in the particulate fraction, indicating erosion as the primary process associated with nutrient loss.

The time- post liquid dairy manure affected runoff, sediment and nutrients losses (except nitrate-N). In our research, the 24 h

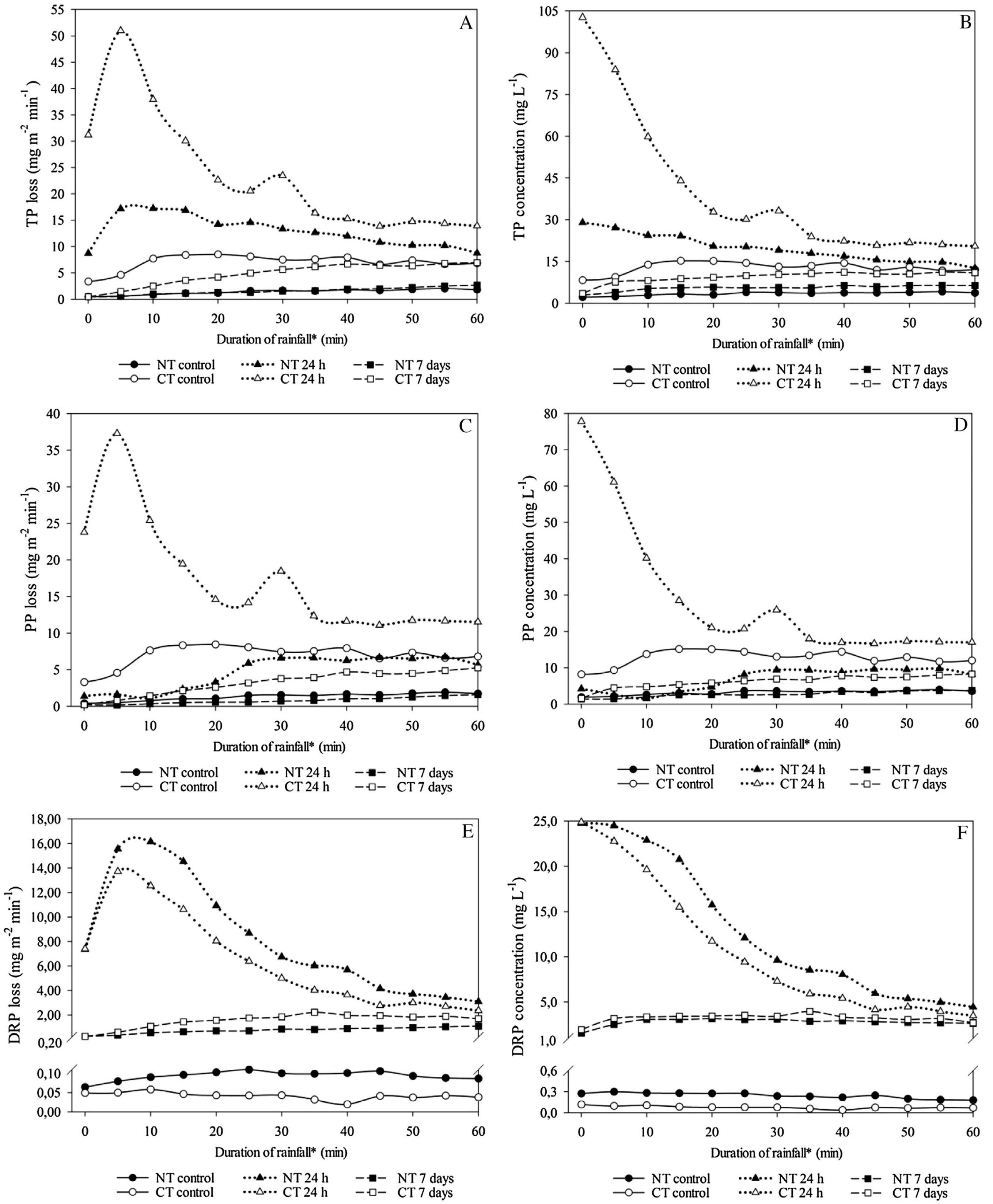

Fig. 2. Total P (A, B), Particulate P (C, D), and DRP (E, F) under a single rainfall (~50 mm h^{-1}) for 1 h in conventional tillage (CT) and no-till (NT) and time post-manure application (24 h and 7 days).

post-manure application resulted in higher losses in conventional and no-till systems. Seven days after manure application, the losses were significantly decreased.

This information is important in managing and planning manure applications in order to minimize the nitrogen and phosphorus losses, mainly for those in the particulate fractions (sediment-

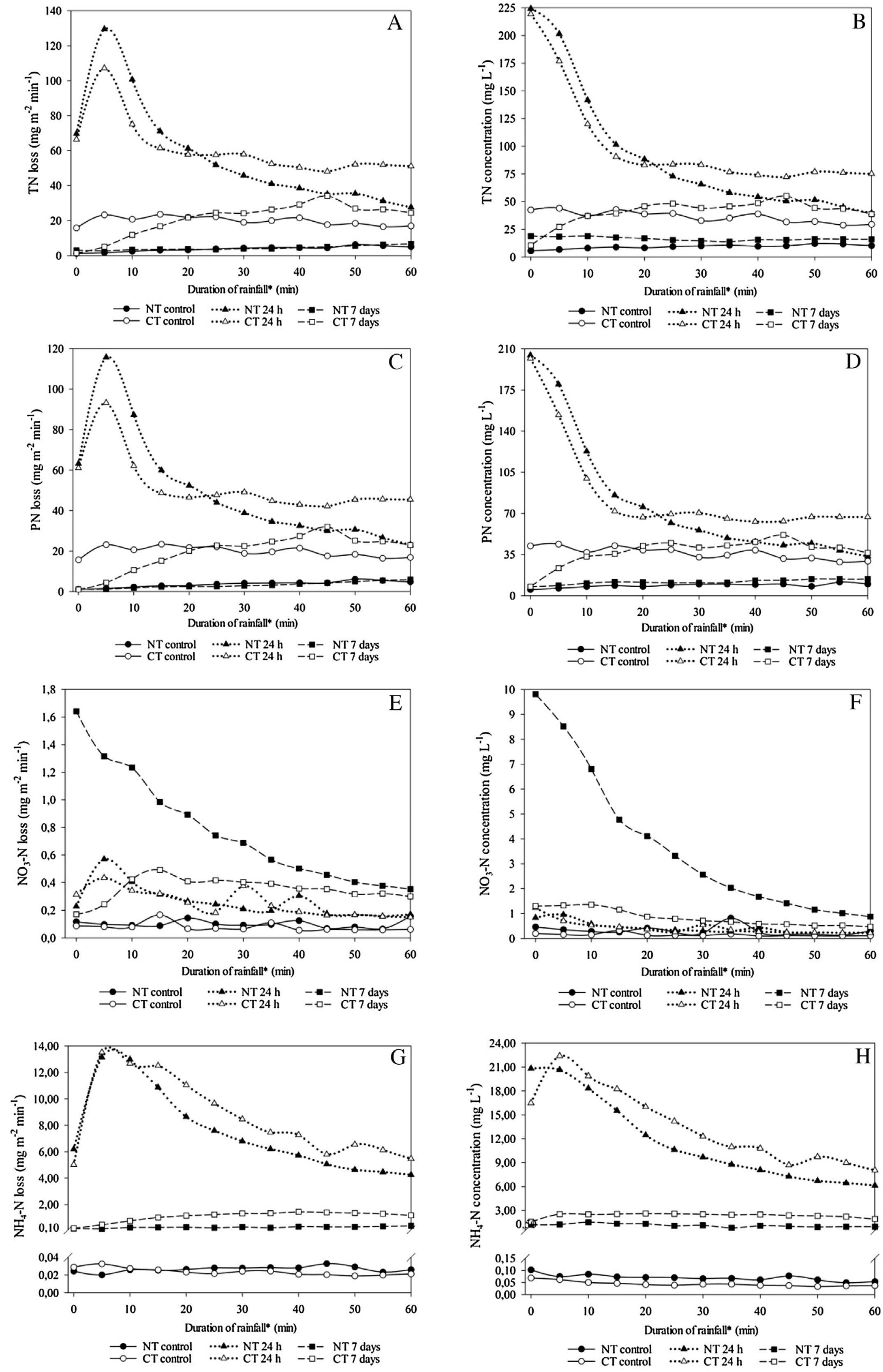

Fig. 3. Total N (A, B), Particulate N (C, D), NO_3-N (E, F), and NH_4-N (G, H), under a single rainfall (~50 mm h^{-1}) for 1 h in conventional tillage (CT) and no-till (NT) and time post-manure application (24 h and 7 days).

Table 4
Cumulative loss and average concentration of dissolved reactive P (DRP), particulate P (PP), total P (TP), soluble NH_4-N, soluble NO_3-N, particulate N (PN), and total N (TN) in runoff for different tillage system and time post-manure application.

	DRP	PP	TP	NH_4-N	NO_3-N	PN	TN
Loss (mg m^{-2})[a]							
CT Control	2.71 d	453.4 b	456.1 c	1.54 d	4.91 b	1279 b	1285 b
CT 24 h	410.9 a	1116 a	1527 a	558.1 a	16.4 ab	3374 a	3948 a
CT 7 days	100.2 b	209.7 b	309.9 c	71.3 b	22.9 ab	1214 b	1308 b
NT Control	6.09 d	85.3 c	91.4 d	1.73 d	6.27 b	230.2 c	238.2 c
NT 24 h	530.2 a	303.4 b	833.7 b	482.7 a	17.1 ab	3194 a	3694 a
NT 7 days	48.8 c	51.2 c	99.3 d	18.5 c	50.8 a	210.2 c	279.5 c
Concentration (mg L^{-1})[a]							
CT Control	0.08 d	12.7 b	12.8 c	0.04 d	0.15 c	36.2 c	36.4 bc
CT 24 h	10.7 a	29.1 a	39.8 a	13.6 a	0.42 bc	86.6 a	100.6 a
CT 7 days	3.22 b	6.21 c	9.43 c	2.35 b	0.83 b	36.5 c	39.7 b
NT Control	0.25 c	3.19 d	3.44 d	0.07 d	0.31 bc	8.62 d	9.18 d
NT 24 h	12.9 a	6.87 c	19.8 b	11.6 a	0.42 bc	79.9 ab	92.0 a
NT 7 days	2.79 b	2.74 d	5.53 d	1.12 c	3.71 a	11.6 d	16.4 cd

CT: Conventional tillage; NT: No-till; Control: treatment without LDM application; 24-h: treatment with LDM and simulated rainfall 24 h after LDM application; 7-days: treatment with LDM and simulated rainfall 7 days after LDM application.

[a] Means followed by the same letter in the column are not significantly different by Tukey's test ($P < 0.05$).

Table 5
Percentage of the total P (TP) as dissolved reactive P (DRP) and particulate P (PP) and of the total N (TN) as ammonium (NH_4-N), nitrate (NO_3-N) and particulate N (PN) for the treatments calculated using the average concentration in runoff for different tillage systems and time post-manure application.

	CT Control	CT 24 h	CT 7 days	NT Control	NT 24 h	NT 7 days
% of TP as DRP and PP						
DRP	0.8	26.9	34.1	7.3	65.0	50.5
PP	99.2	73.1	65.9	92.7	35.0	49.5
% of TN as NH_4–N, NO_3-N and PN						
NH4-N	0.1	13.5	5.9	0.8	12.6	6.8
NO3-N	0.4	0.4	2.1	3.4	0.5	22.5
PN	99.5	86.1	91.9	95.8	86.9	70.6

CT: Conventional tillage; NT: No-till; Control: treatment without LDM application; 24-h: treatment with LDM and simulated rainfall 24 h after LDM application; 7-days: treatment with LDM and simulated rainfall 7 days after LDM application.

associated). Therefore, in practical terms, we would recommend using weather forecast in making decisions on when to apply liquid dairy manure provide agronomic benefits and avoid risk of water pollution.

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References

Adeli, A., Bolster, C.H., Rowe, D.E., Mclaughlin, M.R., Brink, G.E., 2008. Effect of long term swine effluent application on selected soil properties. Soil Sci. 173, 223–235.
Allen, B.L., Mallarino, A.R., 2008. Effect of liquid swine manure rate, incorporation, and timing of rainfall on phosphorus loss with surface runoff. J. Environ. Qual. 37, 125–137.
Barrington, S.F., Jutras, P.J., Broughton, R.S., 1987. The sealing of soil by manure II. Sealing mechanisms. Can. Agric. Eng. 29, 105–108.
Barthès, B., Albrecht, A., Asseline, J., Noni, G., Roose, E., 1999. Relationship between soil erodibility and topsoil aggregate stability or carbon content in a cultivated Mediterranean highland (Aveyron, France). Commun. Soil Sci. Plant 30, 1929–1938.
Beniston, J.W., Shipitalo, M.J., Lal, R., Dayton, E.A., Hopkins, D.W., Jones, F., Joynes, A., Dungaitd, J.A.J., 2015. Carbon and macronutrient losses during accelerated erosion under different tillage and residue management. Eur. J. Soil Sci. 66, 218–225.
Bertol, O.J., Rizzi, N.E., Favaretto, N., Lavoranti, O.J., 2005. Perdas de nitrogênio via superfície e subsuperfície em sistema de semeadura direta. R. Flor. 35, 429–443.
Bortolozo, F., Favaretto, N., Dieckow, J., Moraes, A., Vezzani, F., Silva, É., 2015. Water, sediment and nutrient retention in native vegetative filter strips of Southern Brazil. Int. J. Plan. Soil Sci. 4, 426–436.
Bradford, J.M., Huang, C., 1994. Interrill soil erosion as affected by tillage and residue cover. Soil Tillage Res. 31, 353–361.
Casalí, J., Gastesi, R., Álvarez-Mozos, J., De Santisteban, L.M., Lersundi, J.D.V., Gimenez, R., Larranaga, A., Goñi, M., Agirre, U., Campo, M.A., López, J.J., Donézar, M., 2008. Runoff, erosion, and water quality of agricultural watersheds in central Navarre (Spain). Agr. Water Manage. 95, 1111–1128.
Cherobim, V.F., Favaretto, N., Armindo, R.A., Barth, G., Dieckow, J., Pauletti, V., 2015. Water infiltration post-liquid dairy manure application in no-till Oxissol of Southern Brazil. Soil Tillage Res. 153, 104–111.
Cruse, R.M., Herndl, C.G., 2009. Balancing corn stover harvest for biofuels with soil and water conservation. J. Soil Water Conserv. 64, 286–291.
Culley, J.L.B., Phillips, P.A., 1982. Sealing of soils by liquid cattle manure. Can. Agric. Eng. 29, 105–108.
Eghball, B., Gilley, J.E., 1999. Phosphorus and nitrogen in runoff following beef cattle manure or compost application. J. Environ. Qual. 28, 1201–1210.
Fares, A., Abbas, F., Ahmad, A., Deenik, J.L., Safeeq, M., 2008. Response of selected soil physical and hydrologic properties to manure amendment rates levels, and types. Soil Sci. 173, 522–533.
Hanrahan, L.P., Jokela, W.E., Knapp, J.R., 2009. Dairy diet phosphorus and rainfall timing effects on runoff phosphorus from land-applied manure. J. Environ. Qual. 38, 212–217.
Hatch, D., Goulding, K., Murphy, D., 2002. Nitrogen. In: Haygarth, P.M., Jarvis, S.C. (Eds.), Agriculture, Hydrology and Water Quality. CABI Publishing, Cambridge, pp. 7–27.
Hooda, P.S., Edwards, A.C., Anderson, H.A., Miller, A., 2000. A review of water quality concerns in livestock farming areas. Sci. Total Environ. 250, 143–147.
Johnson, K.N., Kleinman, P.J.A., Beegle, D.B., Elliott, H.A., 2011. Effect of dairy manure slurry application in a no-till system on phosphorus runoff. Nutr. Cycl. Agroecosyst. 90, 201–212.
Kaiser, D.E., Mallarino, A.P., Haq, M.U., Allen, B.L., 2009. Runoff phosphorus loss immediately after poultry manure application as influenced by the application rate and tillage. J. Environ. Qual. 38, 299–308.
Kato, T., Kuroda, H., Nakasone, H., 2009. Runoff characteristics of nutrients from an agricultural watershed with intensive livestock production. J. Hydrol. 368, 79–87.
Kheyrodin, H., Antoun, H., 2011. Tillage and manure effect on soil physical and chemical properties and on carbon and nitrogen mineralization potentials. Afr. J. Biotechnol. 10, 9824–9830.

Kleinman, P.J.A., Sharpley, A.N., 2003. Effect of broadcast manure on runoff phosphorus concentrations over successive rainfall events. J. Environ. Qual. 32, 1072–1081.

Kleinman, P.J.A., Sharpley, A.N., McDowell, R.W., Flaten, D.N., Buda, A.R., Tao, L., 2011. Managing agricultural phosphorus for water quality protection: principles for progress. Plant Soil 349, 169–182.

Lal, R., 2003. Soil erosion and the global carbon budget. Environ. Int. 29, 437–450.

Leinweber, P., Turner, B.L., Meissner, R., 2002. Phosphorus. In: Haygarth, P.M., Jarvis, S.C. (Eds.), Agriculture, Hydrology and Water Quality. CABI Publishing, Cambridge, pp. 29–55.

Lord, E.I., 1996. Pilot nitrogen sensitive areas scheme. Results from the first four years. In: Petchey, A.M., D'Arcy, B.J.D., Frost, C.A. (Eds.), Diffuse Pollution and Agriculture. The Scottish Agricultural Colleges (SAC), Edinburgh, pp. 64–72.

Mcdowell, R.W., Sharpley, A.N., 2002. Phosphorus transport in overland flow in response to position of manure application. J. Environ. Qual. 31, 217–227.

Meijer, A.D., Heitman, J.L., White, J.G., Austin, R.E., 2013. Measuring erosion in longterm tillage plots using ground-based lidar. Soil Tillage Res. 126, 1–10.

Mori, H.F., Favaretto, N., Pauletti, V., Dieckow, J., Santos, W.L., 2009. Perda de água, solo e fósforo com aplicação de dejeto líquido bovino em Latossolo sob plantio direto e com chuva simulada. Rev. Bras. Cienc Solo 33, 189–198.

O'Dell, J.W., 1993. Method 351.2 Determination of Total Kjeldahl Nitrogen by Semi-Automated Colorimetry. In: O. o. R. a. Development (Ed.), 2nd ed. US EPA, Cincinnati.

Ramos, M.R., Favaretto, N., Dieckow, J., Dedecek, R., Vezzani, F.M., Almeida, L., Sperrin, M., 2014. Soil, water and nutrient loss under conventional and organic vegetable production managed in small farms. J. Agric. Rural Dev. Trop. 115, 31–40.

Schroeder, P.D., Radcliffe, D.E., Cabrera, M.L., 2004. Rainfall timing and poultry litter application rate effects on phosphorus loss in surface runoff. J. Environ. Qual. 33, 2201–2209.

Schwab, G.J., Whitney, D.A., Kilgore, G.L., Sweeney, D.W., 2006. Tillage and phosphorus management effects on crop production in soils with phosphorus stratification. Agron. J. 98, 430–435.

Sharpley, A., Wang, X., 2014. Managing agricultural phosphorus for water quality: lessons from the USA and China. J. Environ. Sci. 26, 1770–1782.

Sharpley, A.N., Smith, S.J., Naney, J.W., 1987. Environmental impact of agricultural nitrogen and phosphorus use. J. Agric. Food Chem. 35, 812–817.

Sharpley, A., Jarvie, H.P., Buda, A., May, L., Spears, B., Kleinman, P., 2013. Phosphorus legacy: overcoming the effects of past management practices to mitigate future water quality impairment. J. Environ. Qual. 42, 1308–1326.

Sharpley, A.N., 2003. Soil mixing to decrease surface stratification of phosphorus in manured soils. J. Environ. Qual. 32, 1375–1384.

Smith, D.R., Owens, P.R., Leytem, A.B., Warnemuende, E.A., 2007. Nutrient losses from manure and fertilizer applications as impacted by time to first runoff event. Environ. Pollut. 147, 131–137.

Soil Survey Staff, 1999. Soil Taxonomy. A Basic System of Soil Classification for Making and Interpreting Soil Surveys, second ed. USDA, NRCS, Washington, DC.

StatSoft Inc, 2011. STATISTICA (data Analysis Software System), Version 10. www.statsoft.com.

Tabbara, H., 2003. Phosphorus loss to runoff water twenty-four hours after application of liquid swine manure or fertilizer. J. Environ. Qual. 32, 1044–1052.

Tiessen, K.H.D., Elliott, J.A., Yarotski, J., Lobb, D.A., Flaten, D.N., Glozier, N.E., 2010. Conventional and conservation tillage: influence on seasonal runoff, sediment, and nutrient losses in the Canadian Prairies. J. Environ. Qual. 39, 964–980.

U.S. EPA, 1979. Methods for the Chemical Analysis of Water and Wastes. U.S. Environmental Protection Agency, Washington, DC.

Vadas, P.A., Harmel, R.D., Kleinman, P.J.A., 2007. Transformations of soil and manure phosphorus after surface application of manure to field plots. Nutr. Cycl. Agroecosyst. 77, 83–99.

Verbree, D.A., Duiker, S.W., Kleinman, P.J.A., 2010. Runoff losses of sediment and phosphorus from no-till and cultivated soils receiving dairy manure. J. Environ. Qual. 39, 1762–1770.

Wang, Y.T., Zhang, T.Q., Hu, Q.C., Tan, C.S., 2016. Phosphorus source coefficient determination for quantifying phosphorus loss risk of various animal manures. Geoderma 278, 23–31.