Minimising nutrient losses from poultry litter field heaps

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Executive Summary

Four methods for minimising nutrient losses from poultry litter stored in field heaps during winter were evaluated over a three month period January 2011 – March 2011. The methods were:

1. Litter heaps covered with plastic sheeting
2. Litter heaps covered with plastic sheeting with a shallow soil trench to divert runoff around the heap
3. Litter heaps fully enclosed in plastic sheeting (enveloped)
4. Enveloped litter heaps with a shallow soil trench to divert runoff around the heap

Methodology: The experimental trial employed a randomised block design with each method tested on six field sites located in the Mid-Ulster region of Northern Ireland. Sites were in arable use, with no vegetative ground cover. All sites had a control treatment of bare ground. Facilities were installed at each site to capture surface runoff from the plot area surrounding the heaps. During the study period there was a maximum of nine runoff events, which were sampled and analysed for soluble reactive phosphorus (SRP), total soluble phosphorus (TSP), total phosphorus (TP), nitrate (NO_3), ammonium (NH_4), potassium, pH, conductivity, suspended sediment (SS) and biological oxygen demand (BOD). Particulate phosphorus (PP) was calculated as the difference of TP less TSP. Soil Olsen P, NO_3 and NH_4 concentrations in the soil below the heaps were determined at the start of the study and following the removal of the heaps. For each variable the impacts of the site treatments were tested using a mixed ANOVA model with the poultry litter heap method as fixed treatment effects.

Results: The main findings of the study were:

1. Individual plots varied markedly in their Olsen soil P concentration which covered a wide range from 16 to 140 mg P L^{-1}. Based on the ANOVA, only soil P had a significant positive impact ($p = 0.02$) on the TP concentrations measured in runoff from plots. This effect was found for both soluble ($p = 0.03$) and particulate phosphorus fractions ($p = 0.01$).

2. Compared to the controls the presence of the poultry litter heaps was not shown by the ANOVA to impact on the concentrations of phosphorus in runoff from the plots. For the covered versus enveloped heaps comparison, there was a small positive significant effect of covered heaps on PP concentrations. The shallow trench installed around the

heaps to divert runoff was associated with small but significant increases in TP and PP in runoff (*$p < 0.05$*).

3. The dominant fraction of TON in runoff was NO_3. Compared to the control, poultry litter heaps decreased ($p < 0.01$) TON and NO_3 concentrations but increased ($p < 0.01$) NH_4 concentrations in runoff. These effects were self-cancelling as the nitrogen enrichment potentials in runoff, calculated as the sum of TON + NH_4 were similar in runoff from controls (5.0 mg N L^{-1}) and field heaps (5.2 mg N L^{-1}).

4. Concentrations of TON, NO_3 and NH_4 in runoff were higher ($p < 0.05$) from plots with plastic covered heaps compared to those where the heaps were enveloped in plastic. The presence of the shallow trench resulted in a significant decrease in NO_3 concentration ($p < 0.05$) but had no effect on the concentration of NH_4 in runoff.

5. The presence of litter heaps had no impact on conductivity, BOD or SS in runoff, but slightly decreased ($p < 0.01$) pH from 7.56 for the control mean to 7.40 for runoff from litter heaps. Both the presence of the trench and enveloping of the poultry litter in plastic resulted in a decrease in runoff conductivity ($p < 0.01$) but had no impact on BOD, SS or pH. The absence of any impact on BOD indicates no significant interaction between the litter stored in the field heaps and runoff from the plots. The absence of an effect on SS suggests that the field heaps did not alter erosion from plots.

6. The soil P analyses before and after the field trial demonstrated that the presence of litter heaps had no significant effect on soil Olsen P.

7. There was a small increase in soil NO_3 concentration at 60-90 cm depth under both the covered and enveloped treatments when compared with the control plots ($p < 0.05$), and an increase ($p < 0.01$) in soil NO_3 concentration at 0-30 cm depth under the enveloped treatments. These increases, which were small in magnitude, were attributed to enhanced nitrification in soil due to heat generated by the litter heaps and/or a decreased rate of leaching under the litter heaps.

8. Overall the results of the evaluation indicated that the current management of field heaps in Northern Ireland (Treatment 2 - Litter heaps covered with plastic sheeting) does not pose a significant risk to water quality.

Abbreviations used

AFBI	Agri-Food and Bioscience Institute
ANOVA	Analysis of variance
BOD	Biological Oxygen Demand
DM	Dry Matter
L	Litre
N	Nitrogen
NAP	Nitrates Action Programme
NH_4	Ammonium N
NO_3	Nitrate N
P	Phosphorus
PP	Particulate Phosphorus
SRP	Soluble reactive phosphorus
SS	Suspended sediment
TN	Total nitrogen
TON	Total oxidised nitrogen
TP	Total phosphorus
TSP	Total soluble phosphorus

Statistics

Min	Minimum value
Max	Maximum value
n	Number of samples
*	Difference between treatments significant at $p < 0.05$ level
**	Difference between treatments significant at $p < 0.01$ level
***	Difference between treatments significant at $p < 0.001$ level
ns	Difference between treatments not significant at $p < 0.05$ level
p	Probability
Sig.	Significance level for assessing differences between treatments
SE; Std Err	Standard error of mean

1. Introduction

In their recent review of the uses and management of poultry litter, Bolan *et al*. (2010) noted that land application remained the preferred option for utilising poultry litter as it provides a major source of nitrogen, phosphorus and trace elements for crop production and is an effective amendment for improving soil structure. Poultry litter applied to tillage and forage crops provides consistent yields, similar to those arising from inorganic fertiliser application (Sistani *et al*., 2010; McGrath *et al*., 2010), which Sistani *et al*. (2010) demonstrated was not the case for dairy manure. However if managed incorrectly during storage and land application, the high nutrient content of poultry litter also poses a significant risk to water quality (Bolan *et al*., 2010).

McGrath *et al*. (2005) reported a significant increase from 0.1 to 0.23 mg P L^{-1} in dissolved reactive P concentration in runoff following land application of poultry litter. Felton *et al*. (2003) demonstrated the risk posed by poultry litter field heaps, with NO_3 concentrations in runoff ranging from 2.75 to 9.80 mg N L^{-1} and phosphate concentrations from 0.21 to 10.78 mg P L^{-1}. Ritter *et al*. (1994) found that nitrate concentration in groundwater was greater than 10 mg N L^{-1} in the vicinity of poultry litter heaps with no significant difference in the concentration of nitrate in leachate from covered and uncovered heaps. The presence of poultry litter heaps potentially also impacts on soil P with Zebrath *et al*. (1999) reporting an significant increase in soil P concentration below uncovered field heap to a depth of 180 cm in the soil profile.

These studies highlight the need for the careful storage of poultry litter in order to mitigate the risks posed to water quality. Due to these concerns, the Nitrates Action Programme Regulations (Northern Ireland) 2006 (the 2006 NAP Regulations) regulated field storage of poultry litter in Northern Ireland and, up to 31st December 2010, poultry litter could be stored in compact field heaps that were covered within 24 hrs of placement with impermeable plastic sheeting. In addition, a heap could not be located within a minimum distance of 20 m of any watercourse and field storage was only permitted for a maximum of 180 days.

When these regulations were introduced it was expected that by the end of 2010 an off-farm solution to poultry litter application to land in Northern Ireland would have been identified thereby obviating the need for field storage. However, in 2011, as yet, no off-farm solution is operational in Northern Ireland. The 2006 NAP Regulations expired at the end of 2010 and have been replaced for the period 2011 to 2014 by revised NAP

Regulations (Nitrates Action Programme Regulations (Northern Ireland) 2010). These include an extension for field storage of broiler litter to 30th September 2011. Following discussions with the European Commission in 2010 it was agreed that investigations would be undertaken in Northern Ireland to assess the risk of water pollution from field heaps both under the current rules and using alternative methods of field storage. If the trials demonstrated a risk of pollution, then field storage would be discontinued (DARD-DOE, 2011).

This paper presents the results of field trials which were undertaken early in 2011. Four field storage systems for broiler litter were evaluated on six farms to determine the potential risk of nutrient loss to water if these methods were employed in Northern Ireland.

1.1. Aim & Objectives

Aim: To evaluate methods for the storage of poultry litter heaps in arable fields in Northern Ireland.

Objectives:

1. To evaluate the risk of nutrient loss from poultry litter field heaps over a range of soil types and rainfall events
2. To evaluate the effectiveness of two methods of covering poultry litter heaps for minimizing nutrient loss in runoff.
3. To evaluate the use of shallow soil trenches for minimizing nutrient loss from poultry litter field heaps.

2. Materials & Methods

2.1. Experimental Design

The experimental trial employed a randomised block design with five treatments the (the four methods of storage of poultry litter heaps plus a control of bare ground) located at six different farms across Northern Ireland, which was considered as providing sufficient statistical replication to ensure that the results could be generalised across Northern Ireland. Farms were selected to provide a range of soil types, rainfall characteristics and soil hydrological conditions (Figure 1). Within each farm the five treatments were established in a single field, a minimum of 20 m away from the nearest watercourse. The fields on which the heaps were located were to be planted with either forage maize or wheat in the spring of 2011. All fields had been cultivated in 2010 and so had no vegetative cover during the trial period in 2011. Field sizes and soil types are presented in Table 1 along with their management history. Three of the fields were receiving poultry litter for the first time.

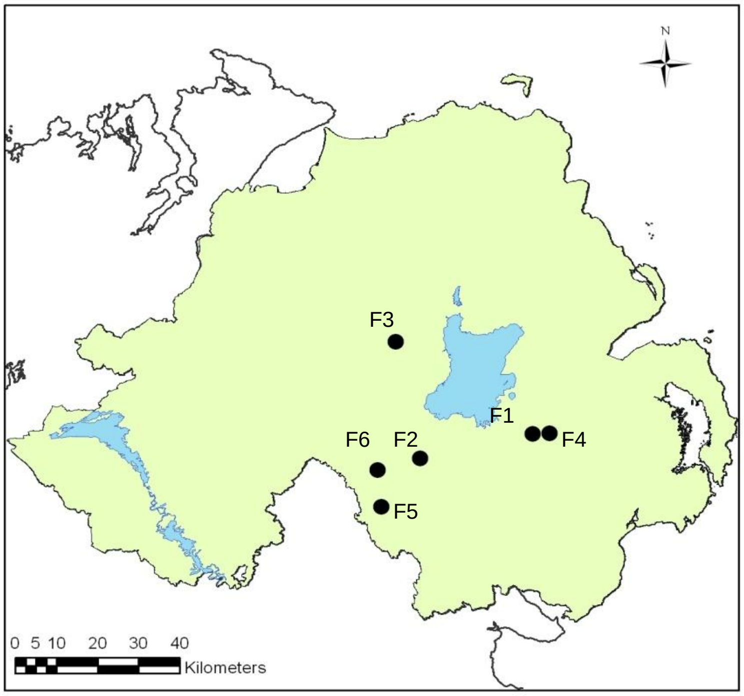

Figure 1: Location of sites for of poultry litter heap storage field trials in Northern Ireland

Table 1: Management and soil type for the six fields in used in the poultry litter heaps field trial

Farm	Field area [ha]	Previous field management	Soil type
F1	10.6	Forage maize sown grown for 4 years	Surface water gley class 1, on Red Trias Till
F2	3.9	Spring wheat for 3 years, then carrots then potatoes	Groundwater gley class 2, on Alluvium
F3	8.0	Spring Barley and winter wheat rotations for 6 years	Brown Earth on Red Trias Till
F4	1.1	Spring wheat for 3 years, then potatoes, then winter wheat	Brown Earth on Sand / Brown Earth on Red Trias Till
F5	4.0	Forage maize 5 years	Surface water gley class 1, on Limestone Till
F6	2.8	Forage maize for 5 years	Surface water gley class 1, on Red Trias Till

The plots were established in January 2011. For each site the poultry litter used originated from the participating farm except in one case (F5) where it was imported. All the poultry litter originated from birds fed on the same diet and with wood shaving used as the main bedding material. Approximately 2.5 tonnes of boiler litter were used in each of the heaps, which were approximately 1 m high and 3 m in diameter and were allowed to settle under their own weight to give an average bulk density of 1078 kg m^{-3}. On each farm the five treatments were established using the following protocols:

Treatment 1 (T1) Control plot:

- No poultry litter heap (background levels of nutrients in runoff).

Treatment 2 (T2) Covered poultry litter heap:

- Poultry litter tipped onto the stubble ground.
- Covered with a plastic sheet (1000 gauge polythene silage cover).
- Plastic sheet weighted down with soil at the edges of the heap.

Treatment 3 (T3) Covered poultry litter heap with shallow soil trench

- Poultry litter tipped onto the stubble ground.
- Covered with a plastic sheet (1000 gauge polythene silage cover).
- Plastic sheet weighted down with soil at the edges of the heap.
- A shallow trench dug around the up-slope edge of the heap at a distance of 1 m from the edge of the heap.

Treatment 4 (T4) Enveloped poultry litter heap

- Poultry litter tipped onto a plastic sheet (1000 gauge polythene silage cover) and enclosed within the sheet.
- The plastic then pulled up and over the sides and the top of the heap.
- Plastic sheet weighted down with soil at the edges of the heap.

Treatment 5 (T5) Enveloped poultry litter heap with shallow soil trench (Figure 2)

- Poultry litter tipped onto a plastic sheet (1000 gauge polythene silage cover) and enclosed within the sheet.
- The plastic then pulled up and over the sides and the top of the heap.
- Plastic sheet weighted down with soil at the edges of the heap.
- A shallow trench dug around the up-slope edge of the heap at a distance of 1 m from the edge of the heap.

Figure 2: Enveloped poultry litter heap and runoff collection point

2.2. Sample Collection and Analysis

2.2.1. Soil and Poultry Litter

Prior to the establishment of each field heap a composite soil sample was taken from the area below the heap to a depth of 15 cm. Soil samples were air dried and analysed for Olsen P, pH and organic matter. Soil core soil samples were also taken in triplicate to a depth of 90 cm from each treatment plot at the six sites and sub-divided into three depths (0-30 cm, 30-60 cm 60-90 cm) which were analysed for nitrate and ammonia following KCL extraction within 24hrs of sampling. The poultry litter at each location was analysed for total phosphorus, total nitrogen and dry matter content. All soil and poultry litter sampling and analyses were repeated following the removal of the field heaps.

2.2.2. Runoff Collection

Figures 2 and 3 illustrate the experimental setup for the collection of runoff from each plot. Soil berms were established down-slope of each poultry litter heap to trap and direct any runoff generated within the plot to a collection point. The berm was positioned approximately 1 m from the edge of the poultry litter heap, and in the case of the treatments incorporating the shallow trench, care was taken to ensure any runoff diverted around the poultry litter heap by the shallow trench was not subsequently collected at the berm (Figure 3). The berms were created with soil from each site, which was compacted and built up to a height of 5-10 cm. Any runoff from the plot was diverted to the lowest point along the berm, where it was collected in a 6” PVC pipe connected to a 20 litre sampling container. The container was covered to ensure rain water did not fall directly into the container and dilute the samples.

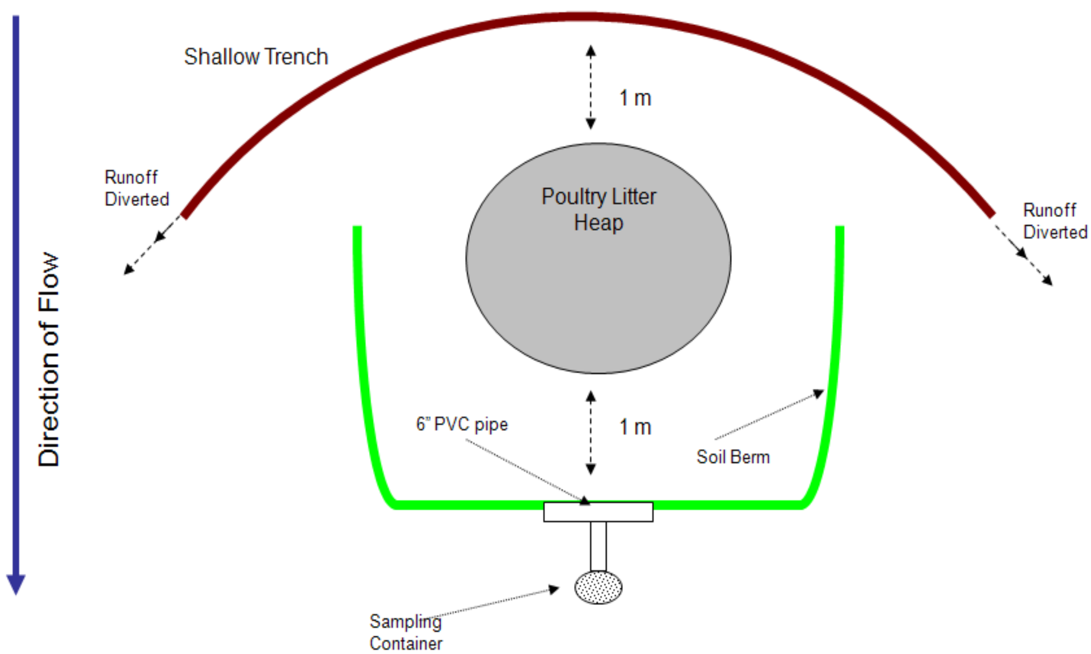

Figure 3: Schematic of the experimental setup for the poultry litter heap field trial

The field trial was carried out over a three month period between the 1st January 2011 and the 31st March 20011. Runoff was collected following rainfall events and, after mixing, a 1 litre sub-sample was taken and refrigerated on return to the laboratory. Runoff samples were analysed for soluble reactive phosphorus (SRP) within 24 hours of sample collection. Samples were also analysed for total soluble P (TSP), total P (TP), total oxidised nitrogen (TON), nitrite nitrogen (NO_2), ammonium nitrogen (NH_4), conductivity, pH, suspended sediment (SS) and biological oxygen demand (BOD). Particulate P was calculated as TP minus TSP. Nitrate N was calculated as TON minus nitrite N. All soil and water analyses were carried out in UKAS credited laboratories within the Agri-Environment Branch of AFBI.

Following sample collection, the runoff collection containers were pumped out and rinsed with deionised water to prevent a build of sediment in the base of the containers and the adsorption of phosphorus to the container. All sub-sampling containers were washed with a phosphate free detergent, rinsed with dilute hydrochloric acid, and again with distilled water.

Predicted rainfall values for each site were obtained from the Meteorological Office.

2.3. Statistical Analysis

Statistical analyses and experimental design were made in conjunction with AFBI Biometrics Branch. Outliers were identified and checked for each variable, and graphics were produced to check the overall data. For each chemical determinant the effect of the five levels of treatments was modelled using a mixed ANOVA model with the poultry litter heap methods as fixed treatment effects. Each farm had all five treatments randomly located on a field site, so the farm (field site) was considered to be a randomised block. The mixed ANOVA model took account of runoff and rainfall characteristics and differences in the physical conditions and management of the farms by modeling the farms and runoff dates as separate random factors, as set out in Equation 1 for each separate variable under study:

$$y = \mu_t + farm + date + \varepsilon \qquad \textbf{(Equation 1)}$$

Where *y* is the physical or chemical measure being modelled, *farm* and *date* are random effects for the farm and unique dates of runoff events normally distributed with mean values of zero and variances of σ_{farm}^2 and σ_{date}^2. The error term ε is distributed with a mean of zero and variance as σ_e^2.

Mean treatment values were estimated with standard errors of the individual treatment levels. Fixed effects were tested to determine if differences between treatments occurred. Pair wise analyses were carried out on individual means to determine if differences occurred between each pair of means. Analyses were carried out with and without the control treatment included. Contrasts were produced to test for differences in combinations of means of, for example, the covered and enveloped treatments if the treatments were different from the control plots.

All statistical analyses of runoff events were made using IBM SPSS Statistics Version 19. Student's paired *t*-test analyses (MS Excel) were also carried out on the soil test and poultry litter analysis data to compare changes in soil and poultry litter parameters over the period of the field trial. The soil nitrate and ammonium data for the covered plots (T2 & T3) were combined and the data for the enveloped plots (T3 & T4) were combined and compared against the soil nitrate and ammonium concentrations in the control plots at the end of the study. The soil P data were combined into covered and enveloped treatments and compared against soil P concentrations in the plots prior to the start of the study.

3. Results

3.1 Soil P

At the start of the study Olsen soil P values for the plots ranged from 16 to 140 mg L^{-1} (Table 2 and Annex 1). Plots on F5 had particularly high with an almost three fold variation in soil P between the six plots on this field. Each field had been previously tested for soil Olsen P by the respective farmers and it is note-worthy that the high soil P values and the high variability in soil P were much less in evidence in the composite field samples for F5 and F6.

Table 2: Average Olsen P concentrations of the plots on which the poultry litter heaps were established and the Olsen P index of the whole field use in the study

Soil P at the start of the study					
	Olsen Soil P (mg L^{-1})			Soil P index	
Farm	**Plot Mean**	**Plot Min.**	**Plot Max.**	**Average for Plots**	**Field value**
F1	37.4	35.7	44.6	3	2
F2	26.2	16.7	35.2	2	1
F3	47.6	32.4	50	4	2 / 3
F4	31.0	18.9	42.8	3	3
F5	82.0	53.8	140.1	5	3
F6	67.5	54.6	76.8	4	3

3.2 Rainfall and runoff

Nine runoff events occurred between 1st January and 31st March 2011 when the poultry litter was removed, surface applied to the fields and subsequently ploughed into the soils. A total of 189 water samples were analysed from the six sites during this time. There was an east-west gradient in predicted rainfall at the sites during the study (Table 3).

Table 3: Predicted rainfall for each site during the period of the field trials.

	Rainfall (mm)			
Farm	January	February	March	Total
F1	37.5	87.5	37.5	162.5
F2	37.5	87.5	37.5	162.5
F3	87.5	125	37.5	250
F4	37.5	87.5	37.5	162.5
F5	37.5	87.5	37.5	162.5
F6	37.5	87.5	37.5	162.5

Total predicted rainfall ranged from 250 mm at the F3 site to the west of Lough Neagh to 162 mm for sites F1, F2 and F4 which were located further east. Rainfall totals at sites F5 and F6 were 200 mm during the period of the study. February was the wettest month during the study with above average rainfall. March was unusually dry.

3.3. Phosphorus Concentrations in Runoff

Total P concentration in runoff from the plots containing poultry litter heaps ranged from 230 $\mu g\ L^{-1}$ to 5500 $\mu g\ L^{-1}$ with PP contributing between 32 and 49% of the P exported (Table 4).

Table 4: Summary statistics for runoff water quality from the poultry litter heaps and control plots on six farms in Northern Ireland

	n	**Minimum**	**Maximum**	**Mean**	**Standard Deviation**
pH	189	6.4	9.5	7.4	0.5
Conductivity ($\mu S\ cm^{-1}$)	189	190	983	146	145
Suspended sediment ($mg\ L^{-1}$)	188	10	3,547	281	376
BOD ($mg\ L^{-1}$)	189	13	254	58.3	38.7
SRP ($\mu g\ L^{-1}$)	189	8	3,009	280	358
TSP ($\mu g\ L^{-1}$)	189	111	3,726	496	419
TP ($\mu g\ L^{-1}$)	189	230	5,500	1,330	966
TON ($mg\ N\ L^{-1}$)	188	0.01	29.4	2.6	3.9
NH_4 ($mg\ N\ L^{-1}$)	188	0.002	24.7	2.2	3.6
NO_3 ($mg\ N\ L^{-1}$)	188	0.003	29.4	2.5	3.8

A feature of the data was the high variability in measured concentrations of the phosphorus fractions, so that, for example the standard errors of the treatment TP means shown on Table 5 were high, ranging between 16 and 29% of the mean concentrations. Plots of the temporal changes in TP concentration demonstrate that on some farms there were high concentrations at the start of the field trials which decreased following rainfall (Figure 4). Peaks in TP concentration occurred throughout the field trials with runoff date causing the majority of the variance in the concentrations recorded.

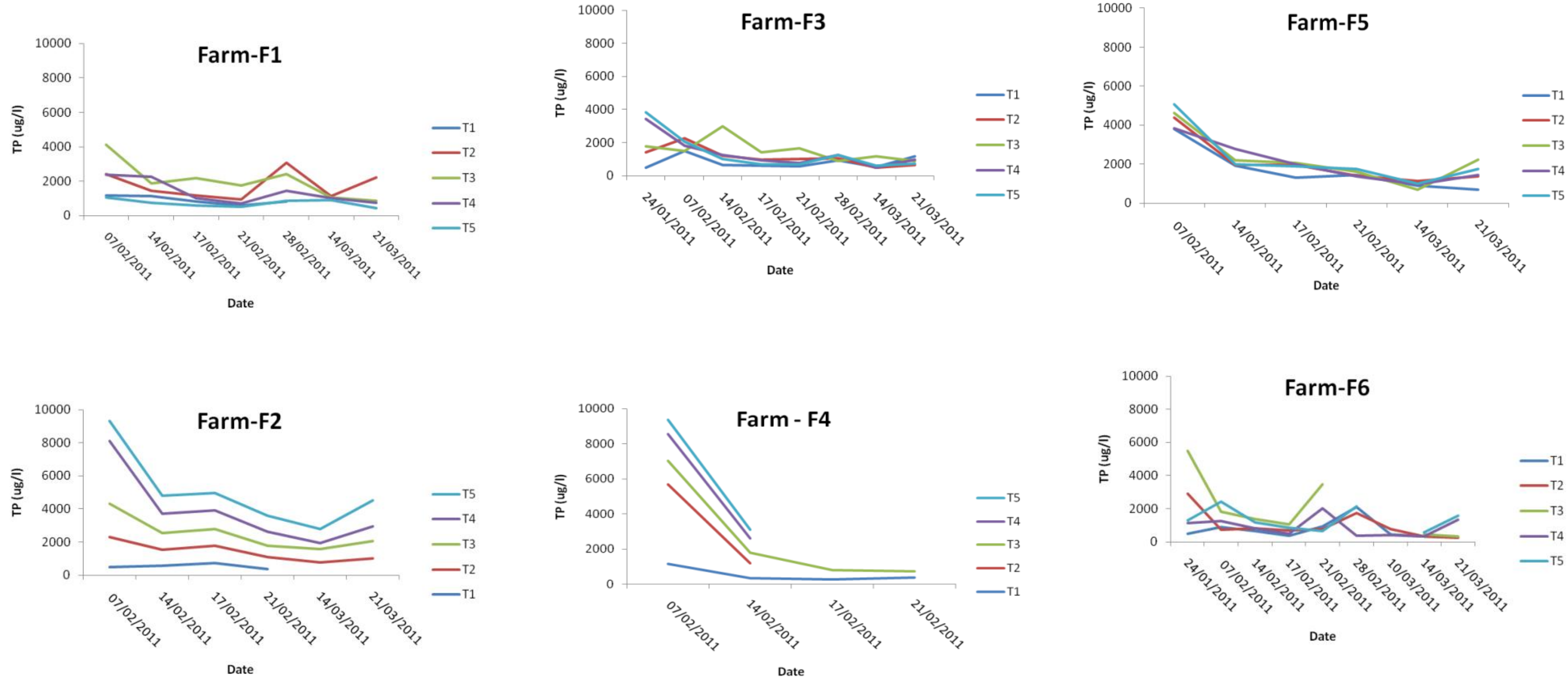

Figure 4 Measured TP concentrations from runoff at each site.

The treatment TP means in runoff from the covered and enveloped plots were 1.6 and 1.4 times higher, respectively, than the mean recorded for the control plots (Table 5). Although the treatment means for SRP, PP and TSP were lowest from the control plots, when all data were statistically compared using the mixed ANOVA model, the presence of the poultry litter heaps was not found to impact significantly on the concentration of any of the P fractions measured in runoff from the plots (Table 5). However the soil P values of the plots did significantly and positively impact on all the P fractions recorded (Table 5). The significance levels for this soil P effect were relatively high so that the TP effect was significant at the p = 0.02 level and p = 0.01 level for PP. The enveloped treatment did show a small but significant positive impact (p = 0.03) on the concentration of PP in runoff when compared with the heaps that were covered with plastic but this effect was not found for either TP or the other P fractions. The presence of a trench was found to significantly increase both TP and PP concentrations but again these effects were small.

Table 5: The effects of poultry litter heaps, method of covering and presence of runoff diversion trench, on soluble reactive P, total soluble P and total P concentration in runoff.

	SRP (μg L^{-1})		**PP (μg L^{-1})**		**TP (μg L^{-1})**	
Treatment	**Mean**	**Standard Error**	**Mean**	**Standard Error**	**Mean**	**Standard Error**
No Litter- Control	153	99	658	203	976	284
Covered	408	98	829	200	1482	282
Covered with trench	474	99	1077	201	1775	283
Enveloped	253	99	884	199	1352	281
Enveloped with trench	311	100	947	206	1452	288
Statistically significant effects between treatments (*ns = effect not significant at p < 0.05*)						
Treatment	ns		ns		0.02	
Soil P	0.03		0.01		0.02	
Litter vs No Litter	ns		ns		ns	
Covered vs Enveloped	ns		0.03		ns	
Trench vs No Trench	ns		0.05		0.03	

3.4. Nitrogen Concentrations in Runoff

In runoff from all plots, nitrate was the dominant component of TON so that treatment difference for TON reflected differences in nitrate concentration (Table 6). The presence of poultry litter heaps resulted in a significant decrease ($p < 0.01$) in NO_3 concentration but a significant increase ($p < 0.01$) in NH_4 concentration in runoff. In magnitude these concentration effects were almost self canceling so there was little difference in TON+NH_4 concentration between control and plots with field heaps (5.02 versus 5.23 mg N l^{-1}). NO_3 and NH_4 concentrations were significantly higher ($p < 0.05$) from plots with covered heaps as opposed to those that were completely enveloped in plastic. The presence of the shallow trench resulted in a significant decrease in NO_3 concentration ($p < 0.05$) but did not significantly affect NH_4 concentration. Figure 5 demonstrates that NO_3 concentrations in runoff from control plots were higher than NO_3 concentrations recorded from the other treatment plots; however peaks in NO_3 concentration from the poultry litter treatment occurred on occasions, but were not accompanied by peaks in BOD. The presence of the litter heap did not alter conductivity, and BOD or SS, however, there was a small significant decrease ($p < 0.01$) in pH associated with poultry litter heaps (Table 7). Both the presence of the trench and the enveloping of the poultry litter in plastic resulted in a decrease in conductivity ($p < 0.01$), but had no impact on BOD, SS or pH.

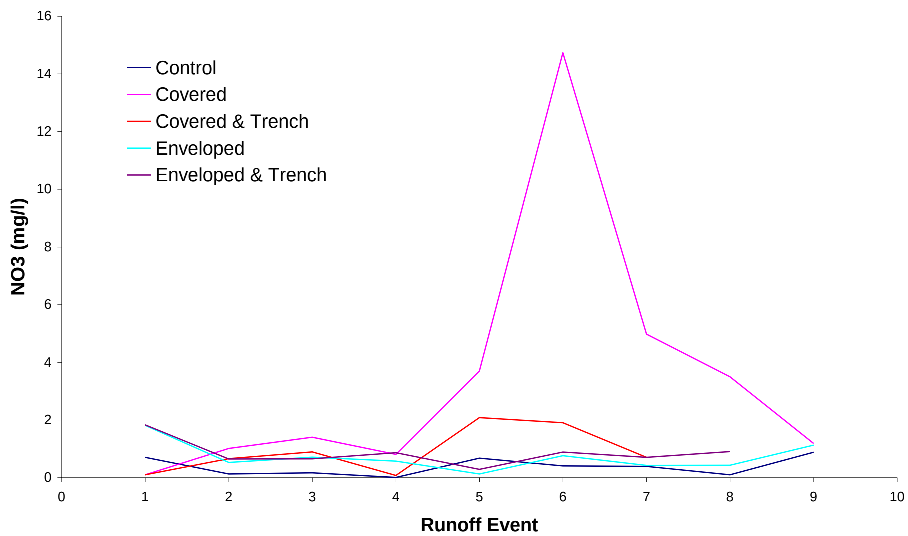

Figure 5: Variation in nitrate concentration in runoff at farm F6 in the poultry litter heaps field trial

Table 6: The impact of poultry litter heaps, method of covering and presence of runoff diversion trench on nitrate, total oxidized N and ammonium concentration in runoff

Factor		NO_3	Std Error	Sig.	TON	Std Error	Sig.	NH_4	Std Error	Sig.
		mg N L^{-1}		*p*	mg N L^{-1}		*p*	mg N L^{-1}		*p*
Litter heap	*No Heap*	4.11	0.85	<0.01	4.17	0.86	<0.01	0.85	0.84	< 0.01
	Litter Heap	2.18	0.69		2.23	0.69		3.00	0.71	
Enveloped	*Enveloped*	1.90	0.87	<0.05	1.96	0.89	<0.05	2.20	0.91	< 0.01
	Covered	2.55	0.87		2.62	0.89		4.02	0.91	
Trench	*No Trench*	2.59	0.87	<0.05	2.65	0.89	<0.05	3.37	0.91	ns
	Trench	1.86	0.87		1.92	0.89		2.86	0.92	

Table 7: The impact of poultry litter heaps, method of covering and presence of runoff diversion trench on pH, conductivity and biological oxygen demand in runoff.

Factor		pH	Std Error	Sig.	Cond.	Std Error	Sig.	SS	Std Error	Sig.	BOD	Std Error	Sig.
				p	µS cm^{-1}		*p*	mg L^{-1}		*p*	mg L^{-1}		*p*
Litter heap	*No Heap*	7.56	.168	<0.01	169	35.4	ns	258	74.7	ns	58.9	8.7	ns
	Litter Heap	7.40	.162		137	30.5		314	54.1		58.6	7.1	
Enveloped	*Enveloped*	7.37	.173	ns	102	34.0	< 0.01	310	57.1	ns	55.5	8.5	ns
	Covered	7.43	.173		182	33.9		310	57.1		63.9	8.5	
Trench	*No Trench*	7.41	.172	ns	169	33.9	< 0.01	261	56.7	ns	55.7	8.45	ns
	Trench	7.39	.173		113	34.0		359	57.6		63.7	8.55	

3.5 Soil effects

The soil P analyses carried out before (treatments were applied) and after the field trials demonstrated that the presence of litter heaps, whether covered or enveloped, had no significant effect on soil Olsen P concentration (Table 8).

Table 8: Outputs from *t*-test analysis of the differences between in Olsen soil P before and after the removal of the poultry litter heaps

	Control			**Covered**			**Enveloped**		
Soil P (mg P L^{-1})	**Mean**	**SE**	**Sig Diff. (*p*)**	**Mean**	**SE**	**Sig Diff. (*p*)**	**Mean**	**SE**	**Sig Diff. (*p*)**
Before	43.7	8.9	ns	51.5	9.8	ns	49.9	5.7	ns
After	45.6	8.2		48.8	6.6		46.3	5.9	

Due to high stone contents in the soil at two sites it was not possible to take a complete soil core to a depth of 90 cm, so only four of the sites were included in the data analysis for changes in nitrate and ammonium concentration in the soil profile. There was a small but significant increase in soil NO_3 concentration at 60-90 cm depth under both the covered and enveloped treatments when compared with the control plots (p < 0.05) (Table 9). In addition there was a significant increase (p < 0.01) in soil NO_3 concentration at 0-30 cm depth under the enveloped treatments.

Table 9: Nitrate and ammonium concentrations in the soil profile below the covered (T2 & T3) and enveloped (T4 & T5) poultry litter heaps following removal of the poultry litter heaps. Values denoted * (p < *0.05*) *and* ** (p < *0.01*) were significantly different from concentrations recorded in the control plots.

Treatment	**Soil depth**	**N0$_3$ (mg N L^{-1}) Mean**	**SE**	**NH$_4$ (µg NL^{-1}) Mean**	**SE**
Control	0-30	4.1	0.6	22.5	10.1
	30-60	5.7	1.0	12.0	4.3
	60-90	5.1	0.9	15.7	6.8
Covered	0-30	7.6	2.7	34.1	12.6
	30-60	6.5	1.4	14.6	7.5
	60-90	5.9*	0.8	11.8	4.6
Enveloped	0-30	8.6**	1.7	4.6**	0.9
	30-60	7.2	1.7	11.5	5.3
	60-90	7.9**	1.4	24.6	10.2

There was no significant difference in soil ammonium concentration under any of the treatment at the end of the study (Table 9).

Table 10 presents the % TP, TN and DM for the poultry litter used at each site at the start and end of the field trial.

Table 10: Total P, Total N and dry matter content of poultry litter prior to field storage and following 3 month storage in covered field heaps

	Before			After		
Farm Identifier	% TN (Wet Weight)	% TP (Dry Weight)	% DM	% TN (Wet Weight)	% TP (Dry Weight)	% DM
F1	3.43	1.44	68.04	3.17	1.24	69.34
F2	3.12	1.37	57.65	3.56	1.55	67.71
F3	3.51	1.57	70.01	3.50	1.59	68.22
F4	2.86	1.28	62.37	3.60	1.71	63.33
F5	3.27	1.35	60.96	3.03	1.52	49.30
F6	3.14	1.42	60.85	3.34	1.51	60.52

4. Discussion

The concentrations of TP observed in the current study ranged from 230 to 5500 μg L^{-1}, which is with the expected range for TP concentration in runoff from arable (cultivated) soils in this region. Regan *et al*. (2010) reported TP concentrations of between 500 and 6000 μg L^{-1} from a small scale study of five Irish tillage soils that ranged in Morgan's soil test P 2.8 to 17.5 mg P L^{-1}. (A Morgan soil P test of 17.5 mg P L^{-1} would be approximately equivalent to an Olsen P level of 55 mg P L^{-1} (Foy *et al*., 1997)). Concentrations of TP for edge of field surface runoff losses at an arable site in England were reported by Catt *et al.* (1998) of up to 5980 μg L^{-1} with an annual mean of 1500 μg P l^{-1} for a soil with Olsen P of 22 mg P l^{-1}.

Using the mixed ANOVA model, none of the methods for field storage of broiler litter tested in this study significantly increased P concentrations in runoff when compared to the control plots with no field heaps. Therefore, by inference, the existing method of field storage of broiler litter (T2) used in Northern Ireland does not increase P losses from fields. The impact of higher soil P on increased P concentrations in runoff, which was clearly identified in the mixed ANOVA model, is in agreement with what is now a well recognized positive correlation between soil P and P loss in runoff from both arable and grassland soils, and reported in many studies (Vadas *et al*., 2005; Watson *et al*., 2007).

The importance of soil P as a driver of P loss in this study was in part due to the very high soil Olsen P values measured in some plots. However it is well known that soil P can vary considerably within individual fields (Dampney *et al*., 1997). Similarly McCormick *et al.* (2009) demonstrated that despite standardized management, the soil P values in a grassland field in Northern Ireland ranged from Olsen's P Index 1 to Index 4. The high plot soil P values in this study tended to exceed the field composite sample values of soil P level that were obtained for agronomic purposes and which placed the fields in which the trials took place in soil P indexes 1 to 3. Hence the fields would not be considered excessively enriched with P.

The limited impacts of the other treatment effects listed in Table 5 do not support the installation of trenches to restrict the flow of up-slope runoff around the plots as the installation of trenches actually increased the concentrations of TP and PP in runoff. There was a slight effect in favour of the existing protocol as the PP concentrations in runoff from the enveloped field heaps were higher than those in runoff from the covered field heaps. The increase in PP following the installation of trenches may reflect additional P losses associated with the physical disturbance of the soil when constructing the trenches.

Although the differences were not statistically significant at the $p<0.05$ level, runoff P concentrations in the presence of field heaps were higher than runoff P concentrations from control plots (Table 5). When soil P is excluded from the mixed ANOVA analysis, these differences between control and field heaps are significant. However, the observation, that covered field heaps increase P losses from field sites, has limited support from the literature. A possible mechanism for such an increase is that the impervious covers generated higher rates of runoff which mobilized soil P (via erosion) from the soil used to secure the plastic covers as shown in Figure 2. Felton *et al.* (2007) demonstrated that covering poultry litter heaps increased runoff volume and peak-flow rates when compared to uncovered poultry litter heaps. Runoff volume was increased by approximately 20%, with peak-flow rates increasing by between 11-24% and it was concluded that the increase in runoff volume and peak-flow would impact on nutrient exports through increased soil erosion from the experimental plots (Felton *et al*., 2007). However the heaps in the study of Felton *et al.* (2007) were 5 times larger than the heaps used the current trials and so have would generated much more runoff, and moreover the study was undertaken in Maryland, USA, which has higher intensity rainfall events than occur in Northern Ireland. In the current study (in Northern Ireland), the fact that field heaps had no effect on the concentrations of suspended sediment in runoff, implies that runoff from the covered heaps had not materially influenced soil erosion rates from plots (Table 7).

Other variables measured in runoff support the contention that broiler litter did not come into contact with runoff to any appreciable extent, and in particular, the absence of any impact of field heaps on BOD concentrations in runoff which, for all treatments, were in the narrow range of 55 to 65 mg L^{-1}. If, in some way, soil moisture and/or runoff from upslope had been wetting the covered field heaps (T2 and T3) then significant increases in runoff BOD levels would have been expected, since BOD levels in manures are measured in units of 1000s. For example the Code of Good Agricultural Practice in Northern Ireland (DARD, 2008) indicates that the expected BOD values for cattle and pig slurry range from 17,000-25000 mg L^{-1}.

The dry matter contents of the litter were still high at the end of the study (Table 10) also points to very limited interaction between runoff and litter during the period of field storage. Likewise the litter heaps did not increase the conductivity of runoff, which would have been expected had there been contact between runoff and litter. It should be noted that as broiler litter is drier than other farm yard manures, the volumes of runoff it generates, even if not covered, are much lower than for other manures.

As regards the nitrogen fractions in runoff, the picture is less clear. The presence of field heaps was associated with an increase in ammonium N but a decrease in total oxidisable nitrogen, of which the dominant fraction was nitrate. When combined, ammonium plus total oxidisable nitrogen, represents the nutrient value and hence eutrophication potential of runoff. On the basis of this combined N total, the eutrophication potential of control (5.0 mg N l^{-1}) and field heap treatments (5.2 mg N l^{-1}) were almost identical (Table 6).

Observed changes in soil nutrient levels were small and not indicative of an environmental risk. Soil Olsen P levels, measured before the installation of litter heaps and after their removal, were unaffected by the presence of the litter heaps. Compared to the control plots at the end of the study there were small but significant increases in soil nitrate concentration occurred under both the covered and enveloped field heaps, namely at the 60-90 cm depth under both the covered and enveloped treatments, and at the 0-30 cm depth under the enveloped plots. As these increases took place under enveloped heaps it is difficult to see how they reflect direct leaching of nutrients from the litter as previously reported by Zebarth *et al* (1999) following winter storage of poultry litter in uncovered field heaps over a six year period.

There are two probable reasons why nitrate accumulated under the poultry litter heaps in this study and not on the control plots. Firstly, the internal temperature of the litter heaps would have increased during storage by up to 60^0C (Penn *et al.* 2011; Sagoo *et al* 2007). Although litter temperature was not measured in this study, field litter heaps in Northern Ireland are known to heat up and this would have caused an increase in soil temperature beneath the heaps compared to that in soil on the control plots. Such an increase in temperature would have accelerated the nitrification of soil ammonium to nitrate, thus increasing the concentration of nitrate in the soil profile. Secondly, the poultry litter heaps (covered or enveloped with plastic) would have protected the soil underneath from rainwater infiltration and leaching, and thus reduced nitrate losses from the soil column compared to the situation on the uncovered control plots. However, the low concentrations of soil nitrate observed in this study indicate that after 12 weeks field storage, leaching of nitrate from covered & enveloped heaps does not pose a significant risk to water quality.

5. Conclusions

a) Poultry litter stored in covered field heaps poses a negligible risk to water quality if managed carefully during field heap construction and storage.
b) Enveloping heaps offers no advantage over covering (with a plastic sheet), and likewise installation of trenches to divert up-slope runoff from field heaps is non-advantageous, as in this study it increased phosphorus concentrations in runoff.
c) Neither nitrate nor phosphorus was mobilized from litter heaps into soil during the 3-month field storage period.
d) The main factor controlling P export across all sites was the pre-existing soil P concentration.
e) Correctly situating and managing field heaps in accordance with current NAP regulations should mitigate any risk of increased export of P from fields.

6. References

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Appendix 1. Olsen soil P values (mg P L^{-1}) on the experimental plots before and after the poultry litter trial.

Treatment	Farm	Soil P Before	Soil P After
T1	F1	36.5	36.8
T2	F1	37.7	36.5
T3	F1	44.6	35.5
T4	F1	39.9	39.2
T5	F1	35.7	31.2
T1	F2	22	30.8
T2	F2	33.9	17.3
T3	F2	21.4	29.3
T4	F2	35.2	16.7
T5	F2	31.6	23.5
T1	F3	43.4	46.7
T2	F3	32.4	41.1
T3	F3	43.4	65.2
T4	F3	43.4	56.2
T5	F3	50	54.4
T1	F4	21.5	21.7
T2	F4	23	41.2
T3	F4	26.7	18.9
T4	F4	33.2	39
T5	F4	41.6	42.8
T1	F5	73.8	61.7
T2	F5	140.1	76.3
T3	F5	85.6	79
T4	F5	98.2	83.2
T5	F5	53.8	68.5
T1	F6	65.2	75.6
T2	F6	66.1	68.6
T3	F6	63.5	76.8
T4	F6	71.1	68.1
T5	F6	65.3	54.5