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VOLUMES AND NUTRIENT CONCENTRATIONS OF EFFLUENT PRODUCTS GENERATED FROM A LOOSE-HOUSED WINTERING BARN WITH WOODCHIP BEDDING

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Abstract

In Southern New Zealand there has been an increase in the use of off-paddock wintering systems as an alternative to the traditional approach of grazing winter brassica crops. These off-paddock systems capture and store effluent products that differ in their characteristics depending on the particular system used. The volumes generated and nutrient characteristics of the effluents produced are poorly defined and this means that the associated nutrient values are not easily estimated. We monitored the volumes and nutrient concentrations of the effluents and manures produced by a loose-housed (i.e. without individual cow bedding stalls) deep litter wintering barn utilising woodchip as a bedding material. Effluent and manure products from 5 sources were monitored: drainage through the barn bedding, effluent scraped from the feeding alley, farm dairy effluent (FDE) from the dairy shed and yard, leachate from the silage pad, and the used barn bedding. Total amounts of nutrient per cow from all captured effluent sources in the dairy farm system were equivalent to: 38.4 kg N cow^{-1} $year^{-1}$, 9.6 kg P cow^{-1} $year^{-1}$ and 56.1 kg K cow^{-1} $year^{-1}$. This equates to an annual fertiliser value of \$140 cow^{-1}. The manure products with the highest nutrient concentrations were associated with dung and urine deposition in the feeding alley and on the barn bedding. The largest volumes of effluent were generated by the FDE from the dairy shed and yard, and rainfall falling on the concrete area of the milking yard, feeding alley and silage pad. The total volume of effluent captured by the pond system was equivalent to 4.2 m^3 cow^{-1} $winter^{-1}$ (of which 3.0 m^3 cow^{-1} comes from the barn system) and the volume of spent bedding represented 7.4 m^3 cow^{-1} $winter^{-1}$.

Introduction

In Southern New Zealand there has been an increasing use of off-paddock systems, such as barns or stand-off pads, for wintering pregnant, non-lactating dairy cows. This has been driven by a number of factors including a desire to reduce contaminant losses to water from the traditional wintering system of grazing brassica crops *in situ*. However, wintering barns and standoff facilities generate large volumes of manure and effluent products that must, at some point, be managed (Houlbrooke *et al*, 2012) . The characteristics of the manure and effluent, and their immediate nutrient values, differ between and within systems (Longhurst *et al.*, 2012) and they are not easily estimated or calculated. Before building a new wintering confinement system (e.g. barn, stand-off pad) it is important that farmers understand the type and volumes of effluent that may be produced as this will impact the design of an effluent system and the volume of effluent storage required. It is also important to have an understanding of the nutrient concentrations of the different effluent products generated.

This will influence the use of these products as a nutrient source and will give farmers an understanding of their fertiliser value and their significance as a source of nutrients to water bodies if lost.

To assist with quantifying nutrient volumes and concentrations for one type of system, a monitoring site was established on the Telford Rural Polytechnic's dairy farm located near Balclutha in South Otago, New Zealand. At the time of this study the farm was running three different farming systems (farmlets) for research purposes. One of these systems was a 'Restricted' (RES) farmlet containing 110 cows which were wintered in a loose-housed barn. The aim of our study was to quantify the volume and nutrient concentrations of effluents generated by the loose-housed wintering barn that was used for wintering the RES herd.

Methods of measuring effluent and manure volumes, and obtaining samples for analysis.

Site

The trial was conducted on the Telford Rural Polytechnic dairy farm located near Balcultha, South Otago (latitude -46° 17'; longitude 169° 43'; 17 m above sea level). In 2012 a new 54-bale rotary dairyshed was built to milk 750 cows and a wintering barn and effluent management system was established to accommodate up to 110 dairy cows for around 70 days over the winter months (Figure 1). The barn was also used in spring and autumn to house cows over night when there was a risk of treading damage to wet soils.

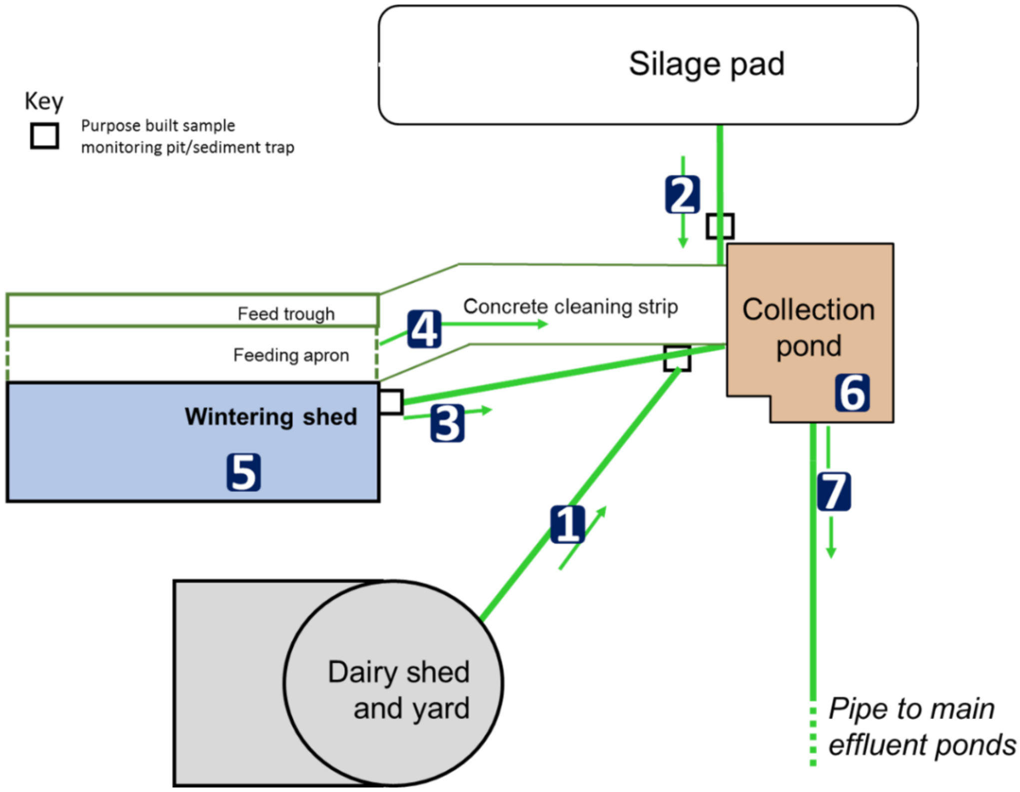

Figure 1: Diagram of the Telford farm effluent and manure measuring sites. These are: 1) FDE, 2) silage pad leachate, 3) effluent draining through the wintering barn bedding, 4) effluent scraped from the feed pad and concrete cleaning strip, 5) barn bedding, and 6) effluent collection pond. Effluent is then pumped via pipe '7' to a large weeping wall for storage in the main effluent ponds.

Wintering barn

The wintering barn is a Red Path Dairyshelter (www.redpath.co.nz; Photo A). It is a loose-housed barn with a clear roof and windbreak along 2 sides of the barn. The base of the barn is a compacted stone and clay layer that is designed to capture all urine excreted via either absorption in the bedding or draining via slotted piping to the effluent system. The bedding used in the barn for the duration of the monitoring was woodchip. Water troughs were located at the ends of the barn (Photo A), although in 2014 these were relocated away from the bedded area and onto the unroofed feeding alley adjacent to the barn.

A. Wintering barn with feeding alley on the righthand side

B. Purpose-built collecting pond

C. Weeping wall in collecting pond

Photos: Wintering barn (A) and purpose built effluent system consisting of a 50 m^3 collection pond (B) that contains a weeping wall with wider than normal slats (C)

Effluent system

The liquid effluent from the wintering barn, silage pad and dairy shed are gravity fed to a small purpose-built collecting pond of 50 m^3 storage capacity (Photo B; Figure 1, point 6). The other source of effluent entering this pond is the solids and liquid effluent scraped from the feeding alley. Solids are scraped every one to two days during the times the barn is in use. The collection pond was designed with a weeping wall (Photo C) to screen out the larger fraction of solids. However, there were issues with the weeping wall blocking and this was eventually removed and not replaced. Liquid effluent is pumped from the collecting pond to the main FDE ponds (13,000 m^3 storage capacity) via two large weeping walls. Effluent is applied to land during spring and summer using a combination of K-line sprinklers and travelling irrigator.

Rainfall collection areas
There is a total of 3,646 m^2 of concreted area capturing rainfall that can potentially enter the effluent system (Table 1). The breakdown of these areas is outlined in Table 1. Both the silage pad and dairy yards have storm water diverters.

Table 1. Concreted areas of the Telford farm that contribute rainfall runoff to the effluent system

Area	Surface area (m^2)
Feeding alley and troughs	432
Dairy shed yards	1,732
Silage pad	1,250
Cleaning strip	198
Effluent pond	34
Total surface area contributing rainfall to the main effluent ponds	3,646

Monitoring sites (Figure 1)
Monitoring sites were established in 2012 to measure the volumes of each effluent stream and also to take samples of the effluent for nutrient analysis:

1. Monitoring of the FDE was via a sediment trap (location 1 in Figure 1) located near the collecting pond. This sump was used for spot sampling of effluent volumes and collections of effluent samples taken eleven times during the milking season.
2. Silage pad runoff volumes were recorded by a five litre tipping bucket connected to a Campbell logger located in a purpose-built sump area (location 2 on Figure 1). There was a collection container that collected 0.3% from each tip and stored it as a composite sample. This was analysed monthly.
3. To monitor the effluent draining through the barn bedding, a pit was located at the southern end of the wintering barn. This housed a three litre tipping bucket that was connected to a Campbell logger that recorded the number of tips the bucket made. There was a composite sample of effluent taken by syphoning 0.3% of each tip into a storage container. The container was emptied and a sample was sent for nutrient analysis on a weekly basis during winter and a monthly basis for the remainder of the year. The bucket was located at the base of the pipe that drained the wintering barn, which in turn drained to the collection pond (location 3 in Figure 1).
4. Effluent was scraped from the feeding alley (location 4 on Figure 1). This was monitored on three occasions carried out at different times during the winter. Here the material from the feeding alley was scraped to form a uniform pile at the end of the alley. The area of the pile was then calculated and a sample taken for analysis and estimate of bulk density.
5. Barn bedding was sampled for nutrient analysis when it was removed from the barn. The volume and number of loads removed were recorded (location 5 on Figure 1).
6. Spot samples of material in the collection pond (behind the weeping wall) were collected weekly during winter.

7. Estimates of the volumes of liquid effluent pumped from the collecting pond to the main effluent ponds were derived by an hour meter installed on the pump (location 7 on Figure 1). This was used to estimate the volume pumped. The hour meter reading was recorded weekly during the winter and less frequently during the milking season. Additionally, the volumes of solids removed by tanker from the pond were recorded as they occurred.

Rainfall was recorded on site by a 0.2 mm increment Davis rain gauge that was logged hourly.

Effluent analysis

Samples for all effluent streams were taken regularly (weekly during winter for wintering barn streams and monthly for the milking season) and were stored at 4°C for a maximum of 48 hours before being sent to a commercial laboratory for analysis of Total Kjeldahl nitrogen (TKN), total P (TP), potassium (K), sulphur (S) and calcium (Ca) (S and Ca data not presented).

Samples of the barn bedding material were taken at the end of the winter and were stored at 4°C for a maximum of 48 hours before being sent to a commercial laboratory for analysis of TN, NH_4^+-N, NO_3^--N, TP, K, S, Ca, Mg, Na, TC, OM, DM, pH.

Results

Rainfall

Total annual rainfall at the site was 686 mm and 726 mm during 2013 and 2014 respectively. The 30-year annual average rainfall for the region for the years 1981-2010 was 679 mm, with an average annual mean air temperature over the same period of 10.4°C (NIWA, 2015). Winter rainfall (1 June – 31 August) was 168 mm and 140 mm in 2013 and 2014, respectively.

Effluent volumes and nutrient characteristics

Rainfall collected in the measurement systems.

Based on the measured annual rainfall, and assuming the dairyshed diverter was in place during June and July, the volumes of rainfall contributing to the effluent system were calculated to be 1017 m^3 and 1075 m^3 in 2013 and 2014, respectively. This assumed that the silage pad diverter was not used.

Effluent volumes collected from the wintering barn

The total annual volume recorded from the wintering barn system in 2013 was 365 m^3, of which approximately 158 m^3 came from the barn drainage, 89 m^3 from the feeding apron and the remaining 118 m^3 from rainfall on the feeding apron and scraping alley. In 2014, monitoring stopped at the end of August; the annual total until this time was 374 m^3, of which 220 m^3 came from the barn drainage, 63 m^3 came from the feeding apron and 91 m^3 came from rainfall that fell on the apron and scraping alley. These volumes are shown on a monthly basis in Figure 2.

Figure 3 shows all effluent streams entering the effluent pond system. This shows that the contribution from the three wintering barn streams was small relative to the volumes of FDE produced at the dairy shed. This volume reflects the volume produced by the 110 cows in the RES herd relative to the 750 cows being milked in the dairy shed.

The volume of FDE produced by the 750-cow herd was estimated to average 32.5 m^3 per day. This was then scaled down to represent the contribution from the 110 RES cows. This was based on;

- 16,000 litres FDE produced per day for the afternoon yard wash
- 12,000 litres FDE produced per day for the morning yard wash
- 2,400 litres FDE produced by the plant wash which was conducted per milking (therefore x 2 a day)
- 2,400 litres FDE produced for vat wash which was done once a day.

Totalling 32,500 litres per day.

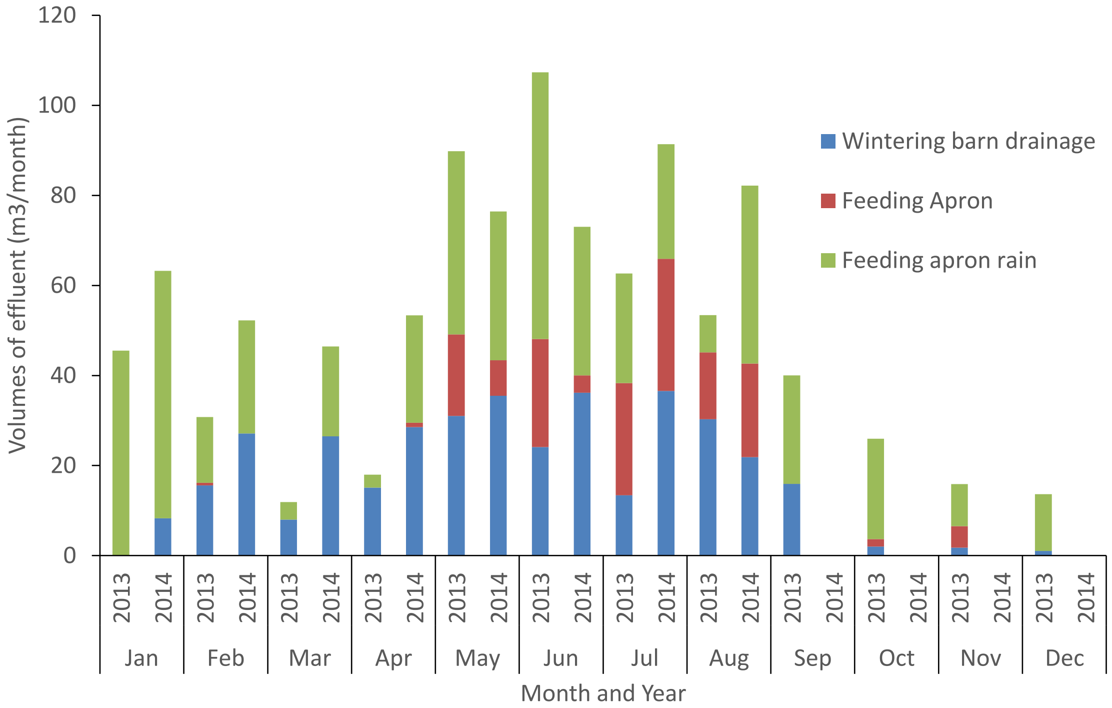

Figure 2: Total monthly volumes of the different effluent streams generated from the wintering barn over two complete winters of monitoring (2013 and 2014).

The results in Figure 2 highlighted a significant problem with the wintering barn drainage. The values recorded appear unrealistically high and there was drainage recorded when there were no cows in the barn. There are two possible reasons for this: firstly, the monitoring equipment could have been faulty. Secondly, there could have been extra liquid entering the wintering barn and thus the effluent system. Calibration of the monitoring equipment ruled out the first possibility. Analysis comparing daily rainfall with the daily volumes drained from the wintering barn (results not shown) showed a clear relationship between rainfall and leachate volume. Looking at one period of our results where there was a reasonable number of consecutive days where cows were housed for 24 hours a day and no rainfall was recorded enabled the calculation that leachate generated by the barn was, on average 1.8 L cow^{-1} day^{-1}, or 9% of the expected daily urination volume.

The total drainage from the wintering barn from 1st January 2014 until 2nd September 2014 was 220 m^3. During the time the cows were in the shed, the expected total volume of urine deposited was estimated to be 154 m^3; assuming only 9% of this volume would have drained, we estimate drainage from the wintering barn should have been approximately 14 m^3. The additional volume collected (over and above the expected volume of 14 m^3) represents over five times the capacity of the collection pond.

The solids scraped from the feeding apron were calculated to represent 0.79 m^3 day^{-1} for 110 cows using the barn 24 hrs day^{-1}. This was calculated from a measured average of 7.18 litres cow^{-1} 24-hours^{-1}. Total solids entering the effluent system from the feeding apron were 89 m^3 in 2013 and 63 m^3 from Jan-Aug 2014 (Table 2).

The silage pad produced 190 m^3 of runoff in 2013 and 212 m^3 from Jan until Aug 2014 (Table 2). Based on the rainfall recorded and the collection area of the silage pad we calculated that the volumes of runoff generated would have been of 858 m^3 in 2013 and 625 m^3 in 2014 (Jan-Aug). This discrepancy between the calculated volumes produced and the recorded volumes captured suggests that the storm water diverter was used for a large proportion of the year.

The liquid pumped from the collection pond to the main FDE ponds was estimated by subtracting the volume of pond sludge removed from the collection pond from the total volumes of effluent entering the collection pond (Table 2). Dairyshed FDE produces the largest volumes of effluent captured by the effluent system (Figure 3).

The final effluent source was the barn bedding itself. This does not enter the effluent pond system but is a significant source of nutrients. In 2014 there was 550 m^3 of spent bedding removed from the barn (the volume removed in 2013 was not recorded). Of this total, 215 m^3 was removed in mid-June, and the remaining 335 m^3 removed at the end of the winter, totalling the equivalent of 7.4 m^3 cow^{-1}. This material had a bulk density of 675 kg/m^3 and a dry matter percentage of 35%. The total produced on a dry weight basis was thus 130 T or 1.7 T cow^{-1} yr^{-1} and on a volume basis was 2.6 m^3 cow^{-1} yr^{-1} (based on an average of 74.5 cows day^{-1} in the barn over the period of use).

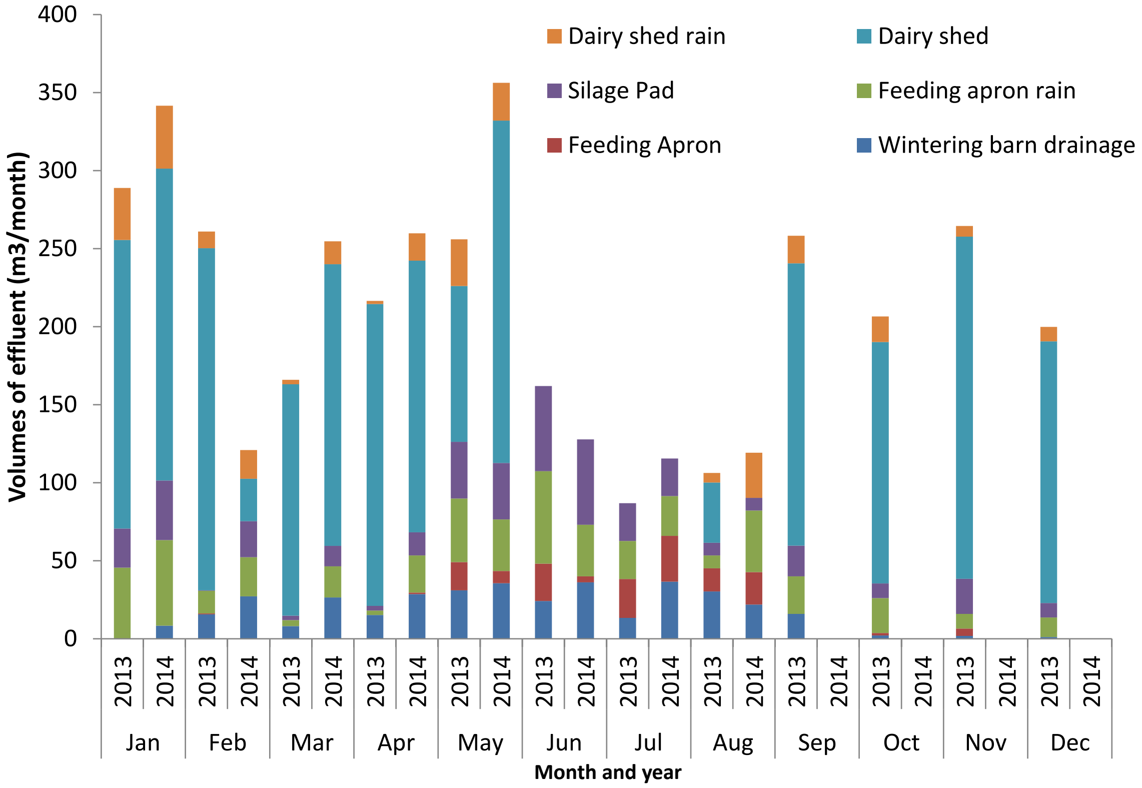

Figure 3: Estimates of the total volumes of effluent entering the Telford effluent collecting pond; scaled for the 110 cows of the RES herd.

Table 2: Effluent streams and products entering and leaving the effluent collection pond in 2013 and Jan-Aug 2014 (m^3). Measured values are in bold and calculated values in italics.

Effluent source	2013 (m^3)		2014 (Jan – Aug) (m^3)	
Effluent streams entering the pond system				
	Total volumes recorded	Per cow	Total volumes recorded	Per cow
Wintering barn drainage	**158**	**2.12**[1]	**220**	**3.25**[1]
FDE for 110 cows	*1423*	*12.9*	*801*	*7.3*
Silage pad	**190**	**1.2**[2]	**212**	**1.3**[2]
Solids from feeding apron	**89**	**1.19**[1]	**63**	**8.5**[1]
Rainfall from feeding alley	*297*	*4.0*[1]	*215*	*2.9*[1]
Rainfall from dairy shed	*940*	*8.5*	*722*	*6.6*
Total	3,097	29.9	2,233	29.85
Effluent streams not entering pond system				
Barn bedding			**550**	**7.4**

[1]The average cow numbers in the barn was 74.5 per day over the 70 day winter. [2] 70% of the silage on-farm was fed to the RES herd.

Nutrient loads and values

Due to the additional water in the wintering barn leachate, the concentration of the leachate was more dilute than would be expected. However, the total nutrient load remains the same.

For the farming system monitored, the total annual nutrient load entering the effluent system in 2013 was 12.8 kg N cow^{-1} y^{-1}, 3.8 kg P cow^{-1} y^{-1} and 19.3 kg K cow^{-1} y^{-1} for a period of 70 days use of the barn by an average of 74.5 cows per day. The majority of the nutrient is contained in the solid fractions of the effluent (the feeding apron scrapings and the barn bedding). Minimal nutrient was captured in drainage from the silage pad or from the wintering barn. The silage stack produced negligible N and P, and only 0.2 kg K cow^{-1} y^{-1}. The amounts generated in drainage from the wintering barn were 0.5 kg N cow^{-1} y^{-1}, negligible P and 2.2 kg K cow^{-1} y^{-1} (Table 3).

Table 3: Annual quantities, nutrient concentrations and fertiliser values of different effluent sources generated from a loose-housed wintering barn.

	Nitrogen	**Phosphorus**	**Potassium**	**Total**
Total annual nutrient quantities measured from different sources (kg cow^{-1} yr^{-1})				
FDE	1.8	1.0	1.2	
Silage pad	0.0	0.0	0.2	
Wintering barn leachate	0.5	0.0	2.2	
Feeding apron	10.5	2.8	15.7	
Barn bedding	23.8	5.8	33.8	
Nutrient concentrations				
FDE	204 mg L^{-1}	46 mg L^{-1}	199 mg L^{-1}	
Silage pad	12 mg L^{-1}	3 mg L^{-1}	88 mg L^{-1}	
Wintering barn leachate*	234 mg L^{-1}	31 mg L^{-1}	803 mg L^{-1}	
Feeding apron	4.17 kg T^{-1}	0.96 kg T^{-1}	5.40 kg T^{-1}	
Barn bedding	4.80 kg T^{-1}	1.19 kg T^{-1}	6.82 kg T^{-1}	
Fertiliser value cow^{-1} $year^{-1}$ (assuming \$1.50 kg^{-1} N, \$4.50 kg^{-1} P, \$0.80 kg^{-1} K)				
FDE	$2.70	$5	<$1	$8.66
Silage pad	<$1	<$1	<$1	$0.16
Wintering barn leachate	$1	<$1	$2	$2.72
Feeding apron	$16	$13	$7	$35.20
Barn bedding	$36	$26	$27	$88.84
Total nutrient value of \$140 cow^{-1} y^{-1}				

* Represents the measured concentration of sample from the barn leachate.

The total fertiliser value of the effluent entering the effluent system is \$47 cow^{-1} $year^{-1}$. Adding to this the fertiliser value of the barn bedding (\$89 cow^{-1} y^{-1}), the total fertiliser value of effluent and manure captured by the system monitored is \$136 cow^{-1} $year^{-1}$. The greatest value comes from the solid effluent materials (Table 3).

Discussion

Volumes and nutrient concentrations for different streams

The volume and nutrient concentrations of FDE in our study are similar to those published elsewhere. The average concentration of N in FDE was 204 mg N L^{-1} (<1 – 400 mg N L^{-1}), which is within the range reported by Longhurst *et al*. (2000) of 81-506 mg N L^{-1}. Values recorded for P (46 mg P L^{-1}; range <1 – 218 mg P L^{-1}) were also within the range reported by Longhurst *et al*. (2000) of 21-82 mg P L^{-1}. The value for potassium of 199 mg K L^{-1} (<1 – 640 mg K L^{-1}) is within the range of 164 - 705 mg K L^{-1} reported by Longhurst et al (2000). The volume of FDE per cow used was based on estimates of the volumes of water used for each activity (vat wash, plant wash and yard wash); these averaged 46.9 L per cow per day, are similar to the value of 50 litres per cow reported in a review of the literature of FDE (Houlbrooke *et al.*, 2004). There is, however, less published data on nutrient concentrations and volumes from the silage leachate and the different wintering barn effluent and manure streams.

Silage effluent production (rather than rainfall collected on the storage area) occurs soon after the silage has been cut, peaking at 10 days post ensiling. Ninety percent of the total effluent produced is done so by day 20-26 (Gebrehanna *et al*., 2014) . Concentrations of TKN recorded in the tipping bucket ranged from 1.14 mg N L^{-1} to 21.6 mg N L^{-1} (average 12 mg L^{-1}). The highest values (21.6 and 20.4) occurred in April and May 2013 respectively; other values were less than 10 mg N L^{-1}. The average P concentration recorded in the tipping bucket was 3 mg P L^{-1} and K was 88 mg K L^{-1}. Values in the literature of undiluted (by rainwater) pasture silage effluent have TN values of around 4,000 mg N L^{-1} and TP values of around 800 mg P L^{-}1 (Galanos *et al*., 1995). These are very high compared to our values of 3 mg P L^{-1} (range 17-0.07 mg P L^{-1}). Thus our samples appeared to be highly diluted from rainwater.

Two of the three effluent and manure streams from the barn have similar nutrient concentrations to those reported in the literature, although the systems reported in the literature differ slightly to the loose-housed deep litter barn studied here.

Nutrient concentrations for the solids scraped from the feeding alley were 4.17 kg N T^{-1}, 0.96 kg P T^{-1} and 5.4 kg K T^{-1}. These results are similar to the findings of Houlbrooke *et al.* (2011). They reported values for N, P and K concentrations in scrapings from two feed pads that are slightly higher than our findings (5.33 and 6.28 kg N T^{-1}, 1.14 and 1.37 kg P T^{-1} and 7.38 and 7.87 kg K T^{-1}). However their reported values of nutrient concentrations of N, P and K in solids scraped from a European style wintering barn are slightly lower than our values (3.19 kg N T^{-1}, 0.80 kg P T^{-1} and 4.24 kg K T^{-1}).

The volume of barn bedding measured here (2.6 m^3 cow^{-1} $year^{-}$1, dry material) is less than that estimated by van der Weerden *et al* (2014) of 3.83 m^3 cow^{-1} over an 80 day winter. However, the figures in our study relate to a 70 day winter so the figure could increase to 2.95 m^3 cow^{-1} if they were in the barn for 80 days rather than 70. The percentage of dry material per wet tonne (35%) compares well to the 34% reported for a carbon-rich wintering pad and the 33% reported for a Herd Home bunker with wood shavings. It is also within the range of 20-50% quoted for Covered barns (Longhurst *et al*., 2012; Longhurst *et al*., 2006).

The average concentrations of nutrients in drainage from the wintering barn were 234 mg N L^{-1}, 31 mg P L^{-1} and 803 mg K L^{-1}. There is very little data in the literature documenting liquid draining through a deep litter wintering barn. However, Houlbrooke *et al.* (2011) sampled liquid effluent draining from a HerdHomes® Shelter. The average values they reported were 920 mg N L^{-1}, 130 mg P L^{-1} and 4,170 mg K L^{-1}. It would be expected that our values were lower than a concentrated liquid due to the additional water source entering the drainage from the wintering barn.

Our findings highlight the need to conduct such monitoring over a wide range of dairy farming systems, as there is such a variety of systems used and the effluent contributed by the off-paddock wintering system contributes a significant proportion of the total volume of effluent captured. In this system, 20% of the total volume of effluent captured by the farm effluent system was attributable to the wintering barn. If the runoff from the silage pad is included in the calculation as a component of the wintering barn then this value increases to 29%.

Monitoring and measuring all manure and effluent streams on a dairy farm is a costly and complex exercise. This monitoring trial was conducted on a commercial dairy farm and there were many complications and challenges gathering data.
These included:

1. There was an obvious discrepancy with the volumes of drainage through the wintering barn recorded and those that were expected. An error in the monitoring equipment was ruled out and it was realised that there was an additional source of liquid entering the effluent system. This additional source was approximately 290 m^3 a year which was enough to fill the collection pond nearly 6 times. Rainfall was the likely contributor to this additional volume.
2. Because of this additional volume of water in the wintering barn effluent stream, the concentrations of nutrients recorded are not representative of the actual concentrations coming from the barn. However, assuming there was little nutrient in the rainfall that was collected, then the total load of nutrient produced is relevant.
3. The cost for a flow meter that was able to handle the stones and other solids in the FDE was prohibitively expensive; accurate recording of FDE volumes was thus not possible.

Conclusions

These findings show that there is much nutrient value in manures collected from a loose-housed deep litter wintering barn with a woodchip bedding. The main nutrient sources are in the solids collected from the bedding and the feeding apron. For a dairy system incorporating a loose-housed deep litter wintering barn with a woodchip bedding, the total amount of nutrient captured annually per cow was 38.4 kg N cow^{-1}, 9.6 kg P cow^{-1}, and 56.1 kg K cow^{-1}. This amounted to a fertiliser value of \$140 cow^{-1} $year^{-1}$. The total volume of effluent captured by the effluent system was 28 m^3 cow^{-1} $year^{-1}$, including 2.7 m^3 cow^{-1} $year^{-1}$ and 4.5 m^3 cow^{-1} $year^{-1}$ from the barn leachate and feeding apron (plus apron rain), respectively. The volume of barn bedding was 2.6 m^3 cow^{-1} $year^{-1}$ dry matter (7.4 m^3 cow^{-1} $year^{-1}$ wet weight).

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