VARIABILITY OF EFFLUENT QUALITY AND QUANTITY ON DAIRY FARMS IN NEW ZEALAND

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Abstract

As part of a dairy farm effluent pond monitoring program, effluent flow and key water quality parameters (Total Solids, Total Nitrogen, and Total Phosphorus) were measured at 3 farms in Southland, Waikato and Northland. The results indicate a large variability in effluent flow and quality, both between farms and at each individual farm between different sampling periods. On a "per cow per day" basis, Farm Dairy Effluent (FDE) flow, solids and nutrient amounts varied several-fold. Presence or absence of a feed pad contributing to the FDE management system was found to have a very large impact on overall FDE solids and nutrient load.

For "all grass" farms without a feed pad the average FDE flow, solids and nutrient figures recorded during this study were within the rather broad range of FDE quantity and quality guideline figures used by the NZ dairy industry. The single farm with a feed pad monitored recorded "per cow per day" FDE solids and nutrient amounts 3 to 5-fold larger than the "all grass" farms.

As dairy farming in NZ continues to intensify and effluent management systems become more sophisticated and complex, accurate knowledge of FDE quantity and quality, and the variability of these parameters will become ever more important. Wherever possible, site specific FDE data from a series of composite samples should be used for designing and operating FDE management systems. Obtaining more data about the contributions and potential effects of feed pads on FDE management systems has been identified as an urgent priority by this study.

Introduction

Better management of dairy farm effluent is a key priority for the New Zealand dairy industry, regulatory bodies and the public. Farmers spend millions of dollars annually to improve effluent treatment systems, effluent storage systems and effluent land irrigation systems. This is, in part, driven by the economic imperative to realize the maximum value represented by effluent fertilizer nutrients, and in part by the increasing need to reduce nutrient losses to ground and surface water, driven by increasing environmental awareness among farmers and the NZ public, and ever tightening effluent management regulation enforced by regional councils. In this regard the use of effluent storage ponds for deferred effluent irrigation is likely to become a near universal practice in the near future.

At the same time farming practices are changing rapidly, with the use of feed and stand-off pads, imported feed supplements, higher stocking rates and longer lactation periods becoming widespread. These changes will present additional challenges for proper effluent management and potentially outdate "standard industry figures" for effluent characteristics, volumes and effluent nutrient concentrations. However, accurate knowledge of these parameters is important not only for the design of effluent systems, but also for appropriate system operation and the assessment of secondary effects, such as Greenhouse Gas (GHG) emissions (e.g. methane from manure), targeted fertilisation, and minimisation of nutrient losses. The most widely used "standard industry figures" for farm dairy effluent (FDE) (milking shed effluent) are derived from only a very limited number of data sets, namely Vanderholm (1984) and the Dairying and the Environment Committee (DEC) (2006). The key figures FDE flow and daily per cow total solids (TS), total nitrogen (TN) and total phosphorus (TP) excretion at the cow shed from both data sets are listed in Table 1. These datasets are also the main information source for more recent NZ dairy effluent literature and tools, such as the Dairy NZ / IPENZ Practice Note 21 (IPENZ 2013) or the Farm Dairy Effluent Storage Calculator (Horne et al. 2009). The FDE figures of Vanderholm (1984) and DEC (2006) appear somewhat lower than international figures for milking shed effluent, such as the figures of Burke (2001) (Table 1), however this could be a reflection of dairy cow live weight being higher in many overseas dairy production systems.

Table 1: Key industry guideline figures for cow shed effluent for FDE flow, Total Solids (TS), Total Nitrogen (TN) and Total Phosphorus (TP) by various authors.

Source		Vanderholm (1984)	DEC (2006)	MfE (2012)	International Burke (2001)^
Average flow	(L/cow/day)	50	50	18^{-}	
Flow range	(L/cow/day)	20 - 90	30 - 100	-	38 - 114
Average solid	(kgTS/cow/day)	0.36	0.55	$0.20^{\#}$	
Solids range	(kgTS/cow/day)	? - 0.55	0.3 – 0.6	-	0.64 – 0.95
Average TN	(gTN/cow/day)	10.4	22.0*	25.5^{+}	
TN range	(gTN/cow/day)	6.8 - 19.0	7.0 – 30.0*	-	28.6 – 42.9*
Average TP	(gTP/cow/day)	1.76	2.5	-	
TP range	(gTP/cow/day)	1.0 – 2.0	0.5 – 4.5	-	4.5 – 6.7

^Based on a dairy cow live weight of 635kg (heavier than typical NZ JxF breeds).
*TKN only, however in fresh cow shed effluent TKN and TN are very similar.
$^{-}$Calculated based on 0.2kgTS/cow/day faecal dry matter (FDM – see below) and a dilution factor of 90L/kgFDM given
$^{\#}$Based on 900 kgTS/y faecal dry matter (FDM) excretion and 8% deposition in cow shed (Ledgard and Brier 2004)
$^{+}$Based on 116.5 kgTN/y total N excretion and 8% deposition in cow shed (Ledgard and Brier 2004).

A further FDE data set may be derived from the information used to calculate the NZ MfE Greenhouse Gas inventory (MfE 2012), contained in several supplementary work sheets (MAF 2011). The NZ GHG inventory assumes that in 2009 (MfE 2012) the average NZ dairy cow excreted 900 kg faecal dry matter (FDM) and 116.5 kg TN per year. With a lactation period of 270 days and a fraction of 8% (Ledgard and Brier 2004) of FDM deposited at the milking shed, the TS and TN figures listed in Table 1 can be calculated. The GHG inventory also assumes that every kg of FDM is diluted with 90L of wash water when handled through an effluent management system, which allows for the back-calculation of the daily per cow effluent flow (Table 1).

In the past, in particular the MfE solids figures have been questioned as being too low (Saggar et al. 2004, Pratt et al. 2012, Chung et al. 2013), and have consequently been suspected as one of a number of factors most likely causing NZ dairy manure management methane GHG emissions to be underreported (Craggs et al. 2008, Pratt et al 2012). To improve the data basis for the GHG inventory, MPI contracted NIWA through Landcare Research, to gather field data over one year on the organic loading, FDE flow and composition as well as CH_4 emissions from farm dairy effluent deferred irrigation storage ponds in major dairy farming areas with contrasting climatic conditions (Southland, Waikato and Northland) to provide crucial values for an improved inventory methodology in order to calculate more accurate CH_4 emissions from dairy farm effluent management. While the main focus of the study was on manure management methane GHG emissions, the data gathered can also be used to counter check the industry FDE guideline figures, and, due to the fact that effluent was sampled at regular intervals throughout the year, provide new information about the variability of FDE quantity and composition, which is the main focus of this paper.

Material and Methods

Data was collected at 3 dairy farms located in Southland, Waikato and Northland. As far as possible the field studies sought to monitor farms which were "typical operations" and therefore representative of herd size, farming intensity and overall farm operation for each of the selected NZ regions.

The Southland farm was located at Dacre, ~25 km north-east of Invercargill. The farm milked up to 735 Friesian cows as part of an "all grass" based operation. The farm had no feed pad, and effluent from the rotary cow shed and associated holding yard was flushed twice per day to a sump from which it was pumped to an effluent storage pond ~400 m away from the cow shed.

The Waikato farm was situated near Cambridge, 25 km South of Hamilton The farm was much more intensively operated than either the Southland or Northland farms. Up to 586 Jersey-Friesian cross cows were managed in several mobs which calved at different times, so the farm did not experience the typical period without milking during winter. The farm had a concrete feed pad which was intensively used throughout the year. The cows spent about 4 h per day on the feed pad, which meant that per day, the cows at the Waikato farm spent more than twice the time on a sealed surface where manure was actively managed compared to the farms in Southland and Northland. While effluent from the herring bone shed and the associate holding yard was flushed daily, manure from the feed pad was removed 3 times a week with a tractor mounted scraper. Manure from the feed pad was scraped into a common sump where it was diluted with flush water from the herring bone shed and pumped into the deferred effluent irrigation storage pond. During dry weather periods the manure from the feed pad was not scraped into the effluent system, but into a separate bunker, and stored and handled as a solid.

The Northland farm was situated on the edge of the Hikurangi swamp ~ 10 km north-west of Whangarei. The farm milked up to 330 predominately Jersey and Jersey-Friesian cross cows. The farm was an "all grass" operation with no feed pad and very little supplement being fed during the milking season. In early 2013 the farm was hit hard by the Northland drought, and all cows were dried off by the beginning of April, extending the 2013 winter dry period without milking by over one month. The farm used manual hosing with bore water to manage the effluent collected in the herring bone shed and the associated holding yard. It did not use either recycled water or a backing gate.

The number of cows milked was recorded weekly for each of the farms throughout the year. Over the one year monitoring period, farm dairy effluent flow rates and the concentration of Total Solids (TS) and fertilizer nutrients (Total Nitrogen (TN) and Total Phosphorus (TP)) in the effluent were monitored at two-weekly intervals. A 30 m^3 tank was installed on the embankment of each of the deferred irrigation storage ponds to collect the effluent. A flow splitter was installed to channel ¼ of the raw effluent flow into the tank and ¾ into the pond. This enabled one quarter of the raw effluent flow from up to two days milking (depending on rain) to collect as a composite sample in the 30 m^3 tank. To calculate the total raw effluent flow over the sampling period, the final tank water level was measured, multiplied by the tank bottom area and the flow splitting factor (4). The analysis of 2 day composite samples helped to balance the potential differences in effluent quality and quantity on the same day (morning milking vs. evening milking), as well as other short term effects, such as rain showers. At the Waikato farm, which had a feed pad, the sampling event sought to capture alternating 2 day periods with and without a feed pad cleaning event, to be reflective of the general feed pad cleaning regime of 3 cleaning events per week.

Before taking subsamples for laboratory analysis, the composite sample in the 30 m^3 tank was stirred for at least 30 min by a recirculation pump to break up any scum and sludge layers inside the tank and to homogenize the tank volume thoroughly. In addition more stable crust fragments were broken up manually. Once sampling was complete, the remaining volume was drained by gravity into the deferred irrigation storage pond. Samples were stored in clean plastic containers, and returned/couriered to the laboratory for immediate analysis.

All analyses were carried out according to standard methods (APHA 2005). Characterisation for Total Solids (TS) followed Standard method 2540B. Total Nitrogen (TN) was calculated as TKN + Nitrate-N + Nitrite-N for which methods APHA 4500-N_{org} D, APHA 4500 NH_3 F and APHA 4500-NO_3- I were used, respectively. APHA method 4500-P B & E, modified from manual analysis (21st ed. APHA 2005), was used for the analysis of Total Phosphorus (TP).

Results and discussion

Fortnightly monitoring of effluent flow at the 3 farms was conducted from March 2013 to February 2014. During the winter dry season (June and July) no monitoring was carried out at any of the 3 farms. Cow numbers, total daily FDE flow and per cow daily effluent flow for the respective sampling events at the Southland, Waikato and Northland monitoring farms are shown in Table 2.

Table 2: Total daily effluent flow and per cow effluent flow data from the Southland, Waikato and Northland monitoring farm.

	Southland			Waikato			Northland		
	No. of cows	**Total effluent**	**Per cow effluent**	**No. of cows**	**Total effluent**	**Per cow effluent**	**No. of cows**	**Total effluent**	**Per cow effluent**
		m^3/day	L/cow/day		m^3/day	L/cow/day		m^3/day	L/cow/day
Maximum	735	93.2	219	586	79.6	153	330	25.9	92
Minimum	0	17.1	26	150	16.7	37	0	5.2	17
Average	**492**	**47.8**	**74**	**433**	**41.8**	**87**	**203**	**12.1**	**40**
Median		56.0	76		32.5	83		10.2	33
S.D.		20.2	43		18.5	34		6.2	21
Co. of Variation		0.42	0.58		0.44	0.39		0.51	0.54
Week ending									
23/02/2014	728	55.9	77	500	29.9	60	305	20.0	66
16/02/2014	730	64.0	88	500	28.7	57	305	7.6	25
19/01/2014	730	59.7	82	500	42.3	85	305	9.6	31
12/01/2014	730	59.7	82	500	28.7	57	305	13.0	43
22/12/2013	730	59.7	82	512	32.5	63	305	11.7	38
8/12/2013	730			520	79.6	153	305		
1/12/2013	730			520			305	6.2	20
24/11/2013	733	47.8	65	520			305		
17/11/2013	735	48.0	65	520	19.1	37	305	10.7	35
3/11/2013	735	56.0	76	586	31.9	54	305	6.4	21
20/10/2013	734	56.0	76	586	71.7	122	330	19.4	59
13/10/2013	677			586			330	9.5	29
6/10/2013	620	56.0	90	586	65.0	111	330		
22/09/2013	610	24.0	39	560	52.2	93	310	5.2	17
8/09/2013	425	93.2	219	520	59.7	115	300		
25/08/2013	225			480	62.1	129	280	25.9	92
4/08/2013	0			310	16.7	54	220		
26/05/2013	0			220	26.3	119	0		
19/05/2013	550	26.3	48	250			0		
28/04/2013	575	23.9	42	430			0		
21/04/2013	575			430	57.3	133	0		
7/04/2013	580	17.1	29	430	35.8	83	0		
24/03/2013	650	17.1	26	430			220		
17/03/2013	650			450	30.2	67	220		
10/03/2013	700			450	23.7	53	220		

At the Southland monitoring farm the recorded average daily per cow effluent flow of 74 L/cow/day falls within the upper range of guideline values given in Table 1. Daily total effluent flows (47.8 m^3/day on average) were relatively consistent with few outliers recorded, and a marked reduction in effluent flows from March to May, when cows were milked only once every 16h or once a day. From a practical point of view effluent land application and storage is faced with the least challenges during this time of the year, indicating conversely that for the sizing of effluent storage ponds for the most critical time of the year (from the start of the milking season until about October) a slightly higher daily flow number than the recorded average should be used for design purposes.

Compared to Southland, the Waikato monitoring farm recorded a slightly higher per cow daily average effluent flow of 87 L/cow/day, but a slightly lower average daily total flow (41.8 m^3/day); reflecting the lower cow numbers (586 vs. 735). Both, total daily effluent flows and daily per cow effluent flows showed a lot of variability between individual sampling events, which is a reflection of taking 2 day composite samples during periods with and without feed pad cleaning events. The latter lead to a stark increase in total and per cow daily effluent flows, and may be the main reason for the per cow effluent flows at the Waikato farm being the highest of all 3 farms monitored (Table 2).

Technical difficulties prevented the taking of effluent samples at the Northland farm in early 2013, subsequently taking of effluent samples was prevented by the very early onset of the winter dry period due to the 2013 Northland drought. The data form the Northland farm therefore covers only the time period from August 2013 to February 2014. At the Northland monitoring farm, a much lower average total daily effluent flow, and average daily per cow effluent flow of 12.1 m^3/day and 40 L/cow/day, respectively were recorded. Although at a lower absolute level, the variability of flows between sampling events at the Northland farm was similar to the variability recorded at the Southland and Waikato farms (Table 2). The lower effluent flows at the Northland farm, may be explained by the milking shed configuration, and in particular the holding yards being a lot more compact than at the Southland or Waikato monitoring farm, which appears to be reducing flush water use.

Total Solids (TS), Total Nitrogen (TN) and Total Phosphorus (TP) data recorded at the Southland, Waikato and Northland monitoring farm are shown in Table 3. Despite the different geographical location and herd sizes the "all grass" based farms in Southland and Northland recorded rather similar daily per cow TS values, 0.29 and 0.26 kgTS/cow/day on average, respectively, and a similar level of variability between sampling events. At both farms the amounts of TN and TP excreted at the milking shed per cow per day showed a strongly positive correlation with daily per cow TS excretion (Table 3), although the absolute level of TP excretion was higher at the Northland farm. For the "all grass" farms in Southland and Northland the recorded solids and nutrient figures, as well as the daily effluent flow fall within the rather broad range of guideline figures given by Vanderholm (1984) and DEC (2006).

The recorded daily per cow TS, TN and TP figures at the Waikato farm with feed pad were vastly different from the Southland and Northland figures. The average TS (1.13 kgTS/cow/day), TN (54.7 gTN/cow/day) and TP (12.2 gTP/cow/day) figures were 3 to 5 times larger than the respective numbers for the Southland and Northland farm (Table 3)

Table 3: Total Solids (TS), Total Nitrogen (TN) and Total Phosphorus (TP) data recorded at the Southland, Waikato and Northland monitoring farms.

	Southland			**Waikato**			**Northland**		
	Total Solids	**Total Nitrogen**	**Total Phosphorus**	**Total Solids**	**Total Nitrogen**	**Total Phosphorus**	**Total Solids**	**Total Nitrogen**	**Total Phosphorus**
	kgTS/ cow/day	gTN/ cow/day	gTP/ cow/day	kgTS/ cow/day	gTN/ cow/day	gTP/ cow/day	kgTS/ cow/day	gTN/ cow/day	gTP/ cow/day
Maximum	0.50	48.2	4.2	3.79	201.4	53.3	0.38	22.3	4.7
Minimum	0.11	7.9	0.9	0.33	17.9	4.2	0.15	4.5	1.3
Average	**0.29**	**19.3**	**2.5**	**1.13**	**54.7**	**12.2**	**0.26**	**13.7**	**3.1**
Median	0.32	18.2	2.6	0.64	30.4	6.7	0.26	14.5	3.4
S.D.	0.10	9.4	1.0	0.95	45.9	11.9	0.08	5.5	1.1
Co. of Variation	0.36	0.49	0.41	0.84	0.84	0.98	0.29	0.40	0.35
Week ending									
23/02/2014	0.33	21.5	3.8	0.55	26.3	5.6	0.26	22.3	4.1
16/02/2014	0.42	22.8	4.1	1.15	25.2	6.5	0.15	6.7	1.7
19/01/2014	0.34	19.6	3.4	0.58	30.4	4.7	0.15	5.2	1.3
12/01/2014	0.26	17.2	2.9	0.63	32.7	5.8	0.38	12.8	2.4
22/12/2013	0.31	18.8	2.3	0.51	26.7	4.9	0.28	14.6	3.3
8/12/2013				1.67	76.6	19.5			
1/12/2013	0.33	16.4	3.1				0.32	15.7	3.7
17/11/2013	0.28	17.6	2.7	0.81	25.4	5.0	0.25	14.1	3.6
3/11/2013	0.27	19.8	2.6	0.58	29.4	6.7	0.26	15.3	3.5
20/10/2013	0.32	25.9	2.1	3.79	113.8	26.9	0.38	18.8	4.4
13/10/2013							0.21	14.4	2.8
6/10/2013	0.38	28.9	3.2	2.05	95.4	19.2			
22/09/2013	0.13	9.8	0.9	0.64	37.3	8.0	0.17	4.5	1.5
8/09/2013	0.50	48.2	4.2	0.83	48.2	8.2			
25/08/2013				1.27	50.5	10.7	0.31	20.3	4.7
4/08/2013				0.47	29.7	5.6			
26/05/2013				1.73	118.3	25.1			
19/05/2013	0.14	12.9	1.1						
28/04/2013	0.17	11.2	1.5						
21/04/2013				3.20	201.4	53.3			
7/04/2013	0.11	7.9	1.1	0.43	30.0	6.8			
24/03/2013	0.35	9.7	1.7						
17/03/2013				0.35	24.2	5.2			
10/03/2013				0.33	17.9	4.2			

Furthermore the Waikato numbers showed much more variability, with both solids and nutrient values recording 5 to 10-fold differences between sampling events. To some extent this variability reflects the feed pad cleaning regime (3 times per week), causing regular high solids and nutrient loads on the effluent management system. The > 4-fold difference in average daily per cow TS (and nutrients) load between the Waikato farm with feed pad and Southland and Northland without feed pad is surprising, since the cows at the Waikato farm spent less than 3 times the hours per day on a hard surface with effluent management. It is therefore assumed that a substantial secondary TS, TN and TP input in the form of wasted feed was an important contributor to the overall load of the effluent management system at the Waikato farm. While not every on-farm feed pad will be used as intensively as the one at the Waikato farm, and the relative TS, TN and TP contributions of the feed pad to the overall load of the manure management system may be less, the additional load represented by wasted feed should be taken into account when designing effluent storage ponds and pre-treatment equipment or when calculating the adequate size of an effluent irrigation block for optimum effluent nutrient utilisation. We suggest that more monitoring of a larger number of feed pads with different levels of utilisation is required to provide more accurate industry guideline figures on the waste volume, solids and nutrient contribution that feed pads may represent for dairy farm effluent management systems.

The variability in TN and TP numbers between sampling events recorded at all 3 farms furthermore indicates that farms with direct land irrigation are most likely applying manure nutrients rather unevenly over their effluent blocks. However, the increasing use of effluent storage ponds will have a positive side effect in this regard, as it will lead to more balancing and buffering of many discrete volumes of dairy farm effluent, thereby providing a more uniform substrate for land application.

While almost all effluent flow, solids and nutrient figures recorded at the "all grass" Southland and Northland farms fall within the rather broad range of guideline figures provided by Vanderholm (1984) and DEC (2006), some interesting insights can be gained when looking at the relative solids and nutrient ratios recorded at the monitoring farms (Table 4). The measured TN values expressed as a fraction of TS were higher at all 3 monitoring farms than the corresponding figures derived from literature guideline values (Vanderholm 1984, Burke 2001, DEC 2006). This discrepancy was even more pronounced with the TP numbers expressed as a fraction of TS, which were found to be almost twice as high (Table 4) as the same ratios derived from the guideline figures (Vanderholm 1984, Burke 2001, DEC 2006). It remains largely unexplained, why these nutrient ratios were so consistently different from the guideline figures at all 3 monitoring farms. However, these observations may potentially have a great bearing on the design and operation of dairy farm effluent management systems in the field. Due to the simplicity and low cost of analysis, Total Solids (TS) is often the sole effluent quality parameter analysed in many field situations. Effluent nutrient concentrations and amounts are then often extrapolated based on guideline figures. Due to the great variability between sampling events and the potential flexibility in nutrient to solid ratios - as shown by the current monitoring work – the risk of error with this approach may be larger than previously thought. Consequently the extrapolation of FDE nutrient values based on TS analysis should be discouraged. Rather a series of several samples, ideally composite samples obtained over several days / milkings, directly analysed for key effluent nutrients should be used for the design and operation of FDE management systems.

Table 4: Average TS, TN and TP values and relative ratios recorded at the Southland, Waikato and Northland monitoring farm, compared to selected literature numbers.

		Vanderholm 1984	**DEC 2006**	**Burke average**	**Southland average**	**Waikato average**	**Northland average**
Daily TS	(kgTS/cow/day)	0.36	0.55	0.80	0.29	1.13	0.26
Daily TN	(gTN/cow/day)	10.40	22.00	35.75	19.28	54.69	13.73
Daily TP	(gTP/cow/day)	1.76	2.50	5.60	2.53	12.20	3.08
TN / TS fraction	(gTN/kgTS)	28.89	40.00	44.97	**66.26**	**48.21**	**52.54**
TP / TS fraction	(gTP/kgTS)	4.89	4.55	7.04	**8.68**	**10.75**	**11.80**
TP / TN fraction	(gTP / gTN)	0.17	0.11	0.16	0.13	0.22	0.22

Conclusions

The monitoring work carried out for this study has shown that for “all grass” based dairy farms the recorded cow shed effluent flow and solids and nutrient figures were broadly in line with commonly used industry guideline figures, which are still relevant despite farming practices having changed since these numbers were originally collated. The situation is rather different for farms where a feed pad contributes load to the FDE management system. The monitored farm with a feed pad recorded FDE solids and nutrient amounts several-fold larger than the “all grass” farms without feed pads. It should therefore be a priority for the dairy industry to conduct effluent monitoring at a number of feed pad farms, with different levels of utilization, throughout New Zealand, in order to collate a reliable set of guideline figures regarding the flow and solids and nutrient contributions of feed pads to dairy farm effluent management systems. Collating such data is particularly important since the use of feed pads is expected to increase rapidly throughout NZ in the coming years.

A common theme observed with all monitored parameters and at all farms was a great level of variability. Effluent flow, TS, TN and TP amounts and ratios relative to each other varied several fold between individual sampling events as well as between farms, despite the fact that the samples for this study were already obtained as composite samples over 2 days (2 to 4 milkings). It can therefore be concluded that no analysis of FDE should be based on individual grab samples. Rather a series of several samples, ideally composite samples obtained over several days / milkings, should be used as the basis for any FDE analysis or design of an FDE handling and storage system or land irrigation system.

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