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Characterising dairy manures and slurries

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Dave Houlbrooke, Bob Longhurst, Tom Orchiston & Richard Muirhead

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1. Executive Summary

The rapid intensification of dairying in New Zealand since 2000 has lead to increased focus on issues relating to effluent management. Greater cow numbers and use of fertiliser N along with higher supplementary feed inputs on dairy farms has resulted in marked changes in the volume, content and types of effluent produced. The desire to protect pastures and soils from stock damage has also resulted in more management options for removing stock from paddocks. Furthermore, best management practices for land application of farm dairy effluent are now often resulting in solid separation. With all of these system changes, farmers are required to handle effluents and manures that are more concentrated and have higher solid content. This is in addition to coming under increased scrutiny from regional councils concerned about deteriorating water quality. Both the dairy industry and regulatory authorities have not had sufficient New Zealand-based information with regards to these solid effluent types in order to help progress or confirm robust management practices that would provide agronomic and environmental benefit and facilitate the development of sound regulatory policy.

We have defined three different effluent products based on dry matter % with liquids or FDE being < 5% DM, slurry as 5-15% DM and solid manures as > 15% DM. This project examined 22 different case studies to characterise and compare the variability of slurries and manures from different farm and effluent management systems. From this data set some averaged values for dry matter %, Total N, mineral N, P, K, S, Organic C, C/N ratio and % mineral N have been presented for the following effluent management systems:

- Scraped solids
- HerdHomes® Shelter bunker manure
- HerdHomes® Shelter bunker slurry
- HerdHomes® Dairyard
- Carbon rich pads
- Weeping wall solids
- Separated solids

These values, summarised in the following table, can be used as typical or default values as a starting point for expected nutrient content of different effluent management systems. However we recommend this data should be used in combination with either a representative laboratory analytical test of the effluent product to be applied or an Overseer nutrient budget assessment to determine the expected nutrient loading to the block receiving the dairy slurry or manure.

Effluent system	DM %	Total N	Mineral N	Total P	K	Org. C %
Solids (kg/t)						
HerdHomes® Shelter	23.1	5.60	1.56	1.41	6.67	9.7
HerdHomes® Dairyard	27.5	7.37	1.03	1.97	7.59	9.7
Carbon-rich pads	38.2	3.71	0.47	1.08	5.33	14.8
Weeping walls	22.5	2.44	0.25	0.61	0.87	5.0
Mechanically separated	24.7	3.59	0.15	0.59	1.00	10.0
Static screen	11.3	2.30	-	0.43	0.72	-
Scraped – feed pad	25.9	5.92	0.35	1.28	7.69	8.3
Sand trap	30.8	2.00	0.20	0.60	1.3	12.7
Slurries (kg/m^3)						
HerdHomes® Shelter	11.0	4.31	1.67	0.99	6.43	3.7
Scraped – winter barn	8.1	3.19	1.38	0.80	4.24	3.1
Liquids (kg/m^3)						
HerdHomes® Shelter - drained	1.8	0.92	0.59	0.13	4.13	-
Stirred Pond FDE via rain gun	1.7	0.62	0.15	0.13	0.38	0.6

Of the 22 case studies where the manure/slurry was characterised, 17 were also assessed for uniformity of application to the land and their nutrient loading rate. Application uniformity was generally poor from all of the spreading systems assessed compared to the standard (Dairy Effluent Code of Practice) expected for liquid farm dairy effluent using an upper quartile distribution uniformity assessment. Spreading uniformity was better from slurry spreading equipment compared to muck spreaders with their drier and less homogeneous product. Most New Zealand regional council-based environmental standards require liquid effluent to be applied at a rate less than 150 kg N/ha/yr, that was achieved on all but one of the 17 sites chosen for land application case studies. The one exception being a value of 221 kg N/ha from one event which was applied to a cropped maize paddock. In comparison to grazed grassland, cropping N limits should be determined upon crop requirements given the expected yield and also accounting for existing soil mineral N available. As the N requirement for maize is higher therefore a greater amount of N can be applied. In the UK for instance, the maximum N input for cropped land is 250 kg N/ha/yr.

Best management practice for manures and slurries needs to take into account the timing of land application with respect to short term climate and time of year. From a nutrient use efficiency point of view, the application of slurries and manures in late spring provides the optimum window to utilise nutrients for plant growth. Direct loss of P, N and faecal microbes is likely to be greatest during winter and early spring when soils are regularly wetter than field capacity causing drainage and runoff events. Volatilisation losses from surface applied N (not immediately incorporated) will be highest during summer and early autumn when sunshine hours and air temperatures are high. Indirect drainage loss of N from nitrate leaching will be greatest from autumn applied slurry and manure that has only minimal plant growing days prior to the commencement of the winter/spring drainage period, a season when much of the resident soil nitrate N moves below the plant rooting depth and therefore lost to the wider environment. With regards to risk associated with storage and land application off different strength effluents, we feel that slurry products which behave like a liquid should be treated in a similar manner as FDE is taking into account timing of application to different soil types and the degree of sealing required to contain the product during storage. In comparison solid manures can be treated in some aspects like solid fertilisers.

We now have an increased understanding of the different dairy manures and slurries being produced from New Zealand dairy farms and their land application management practices. However, more New Zealand specific research is required if information is to be provided on nutrient transformations and losses during storage, handling and solid separation of slurries and manures and on nutrient losses (water and gaseous) following land application. This would allow development of different application techniques and technologies to be applied in order to manage manures and slurry with diverse characteristics. At this stage manure and slurry management in New Zealand does not appear to be resulting in issues that require a specific targeted policy response, however development of best practices to improve management of dairy farm manures and slurries is urgently required.

2. Introduction

Until recently effluent generated on New Zealand dairy farms has resulted from the wash down of dairy yards after milking with clean water. The product has typically been called farm dairy effluent (FDE). Historically, dairy farms have not produced significant quantities of manures and slurries (accumulated animal wastes in a semi-liquid or semi-solid form), however this situation has changed with recent technology developments in effluent irrigation (DairyNZ 2011, Houlbrooke *et al*. 2004, Houlbrooke and Monaghan 2010, Monaghan et al. 2010), and off-pasture systems (Longhurst et al. 2006). The two main sources of dairy farm manures and slurries are separated solids from FDE and manure collected from feedlots, feed pads and wintering barns/animal shelters. Regional councils have started to require/encourage some storage associated with land application of FDE to minimise adverse environmental effects. This has resulted in the accumulation of higher solid content effluents as it is separated into fractions prior to or during the storage process. The increasing uptake of feed and stand-off pads and animal shelters, while acknowledged as having the potential to minimise adverse environmental effects, has also contributed to the generation of dairy farm sludges and slurries (Longhurst et al. 2006).

According to European classification:

- farm yard manure (FYM) = cattle excreta and bedding material collected during animal housing,
- slurry = scraped cattle excreta and some wash down water collected from dairy yards and animal housing facilities; and
- dirty water = wash down of limited animal excreta and milk spillage from the milking parlour (low nutrient concentration).

New Zealand FDE is analogous to a combination of dirty water and slurry. For the purpose of this report the term effluent will cover FDE, slurry and manure; however the emphasis of this study is placed on the higher solid content effluents such as manures and slurries.

Overseas research indicates that agricultural manures and slurries have potential to result in environmental losses including: gaseous N loss, N leaching loss and surface runoff of P and, to a lesser extent, N (Smith et al. 2000 & 2008). Recommended best management practices to mitigate these environmental effects, increase nutrient use efficiency and decrease pasture fouling have focussed on the importance of timing and loading rates of slurry application and the use of advanced spreading technology to avoid surface broadcasting slurry effluents (Smith et al. 2008). However, little is known about the characteristics of these types of wastes, or the risks that they pose in the context of New Zealand’s environment and unique pasture dominated production systems. As a result, it is difficult to progress policy work that is urgently needed and development of best practices to improve management of dairy manures and slurries.

The three-fold objective of this research is: i) to better characterise New Zealand’s dairy effluent manures and slurries, ii) to identify the existing management practices for applying these products to land, and iii) to assess and develop guidelines for the land application of manures and slurries. These guidelines can then be used by regulatory authorities and the dairy industry as an extension tool to promote best management practices. Best management practices will be sought that achieve both positive agronomic and environmental outcomes.

3. Methodology

3.1 System assessments

This ‘Envirolink tools’ programme sought to characterise a large range of different manure and slurry management systems derived from either solid separation of FDE or the collection of effluent from off-pasture systems. A total of 24 manure or slurry products were characterised covering 8 different generic generation systems spread over 6 different dairy farmed regions of New Zealand (Northland, Waikato, Bay of Plenty, Manawatu, Otago and Southland) (Figure 1). The assessments included the following effluent management systems

- Screw press solid separation
- Weeping wall solid separation (wet and dry)
- Static screen solid separation
- Scraped feed pad solids
- European wintering barns
- Carbon pads (wood chips, bark chips and saw dust)
- HerdHomes® Shelter (wet and dry)
- HerdHomes® Dairyard

Background information about each system was obtained from the farmer including detail such as: number of milking cows, length of milking season, volume of storage available (liquid and solid fraction), operation time for animal off pasture facility, diet of cows and feed intake. The relevant farm operation and effluent system features for each product characterised will be described in detail in a series of case studies presented in the Appendices.

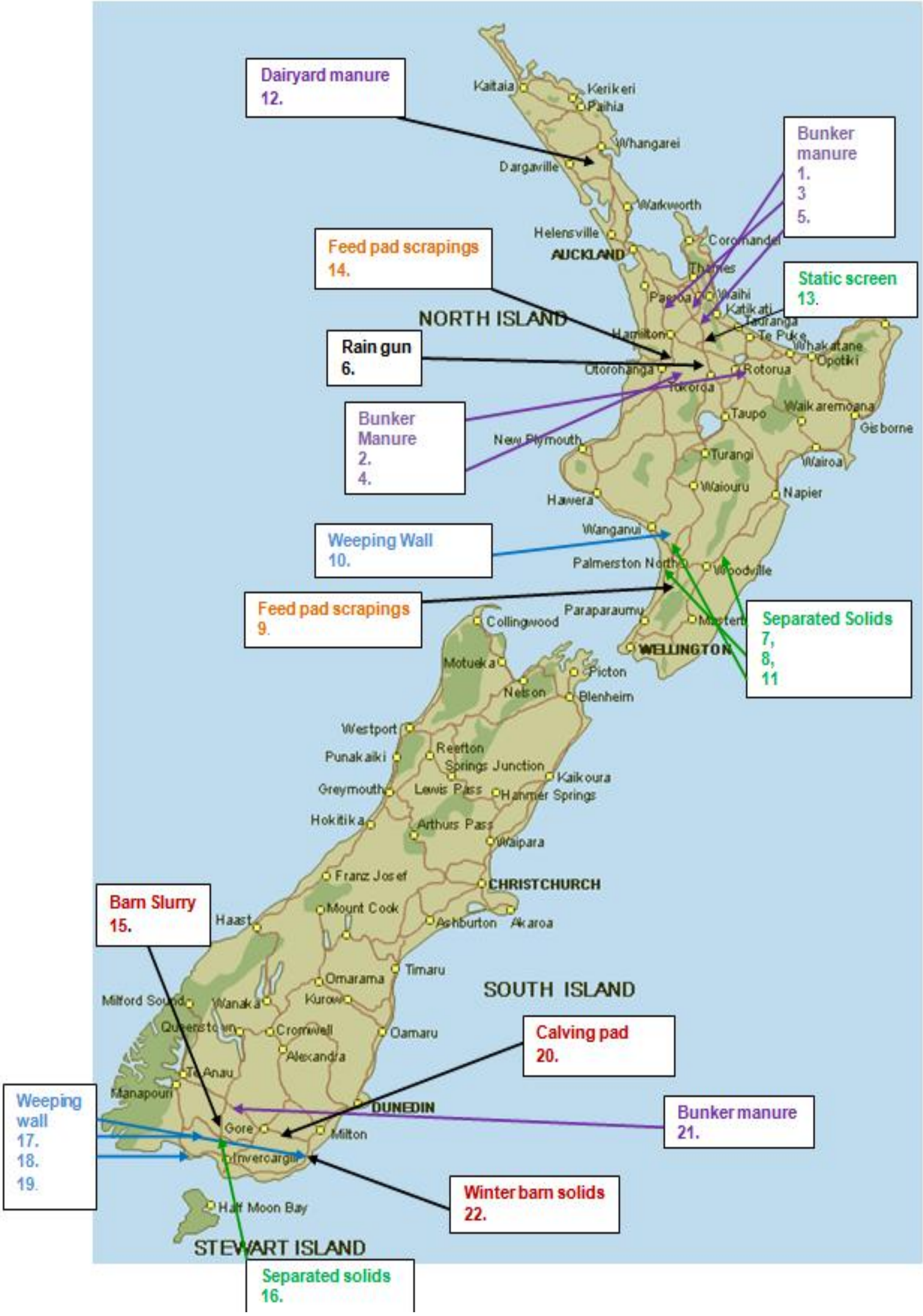

Figure 1: Case study locations and system summary

3.2 Land application data collection

The spreader swath width of each applicator (typically vacuum slurry tanker or muck spreader) was measured during land application using a number of trays across its application footprint. At least three transects were assessed for each application. The number of collection trays used varied between each assessment and are presented for each case study in section 4. The volume and or weight of effluent collected in each tray was determined in the field in order to provide information for calculating effluent depths (mm) and volumes (m^3 ha^{-1}) applied. Typically the volume of effluent was measured if the product behaved as a liquid, otherwise it was weighed.

3.3 Physical and chemical analysis

During land application, a minimum of three well mixed composite samples were collected from each product and used for nutrient characterisation. Sampling the product from trays on the ground subsequent to land application also allowed for some homogenisation to take place while being applied from either a muck spreader or slurry tanker. From each transect (at least 3) a mixed 200 ml sample was collected and sent to an accredited commercial laboratory for analysis of % dry matter (%DM), total Kjeldahl nitrogen (TKN), total phosphorus (Total P), potassium (K), total sulphur (Total S), organic carbon (C), ammonium-N (NH_4-N), nitrate-N (NO_3-N). Test methods used were: Kjeldahl digestion for TKN; HCl/HNO_3 digestion for Total P, K, and Total S; LECO infrared carbon analyser for Organic C; and water extraction (FIA determination) for NH_4-N and NO_3-N. Total N was calculated from the sum of TKN and NO_3-N, mineral-N from sum of NH_4-N and NO_3-N, and organic N (total N – mineral-N).

Most of the chemical analysis was conducted by NZLABS (IANZ) in Hamilton, with the exception of the spatial distribution study (section 5) conducted by ARL (IANZ) and case study 13 (section 4.13) which was conducted by Hill Laboratories (IANZ). Results from the NZLABS were reported in % for everything except NH_4-N and NO_3-N which were reported in ppm. For clarity in this report all data for liquids and slurries are reported as kg/m^3 and for solids as kg/t, as this in the international convention.

At several sites, effluent bulk density (BD) was measured in the field by pouring liquid or slurry into a 250 ml cylinder and weighing it on digital scales. Replicated samples were taken (n=6). The BD data on liquids and slurries was then regressed against %DM to obtain an equation (Figure 2) for converting laboratory units reported in % to kg/m^3.

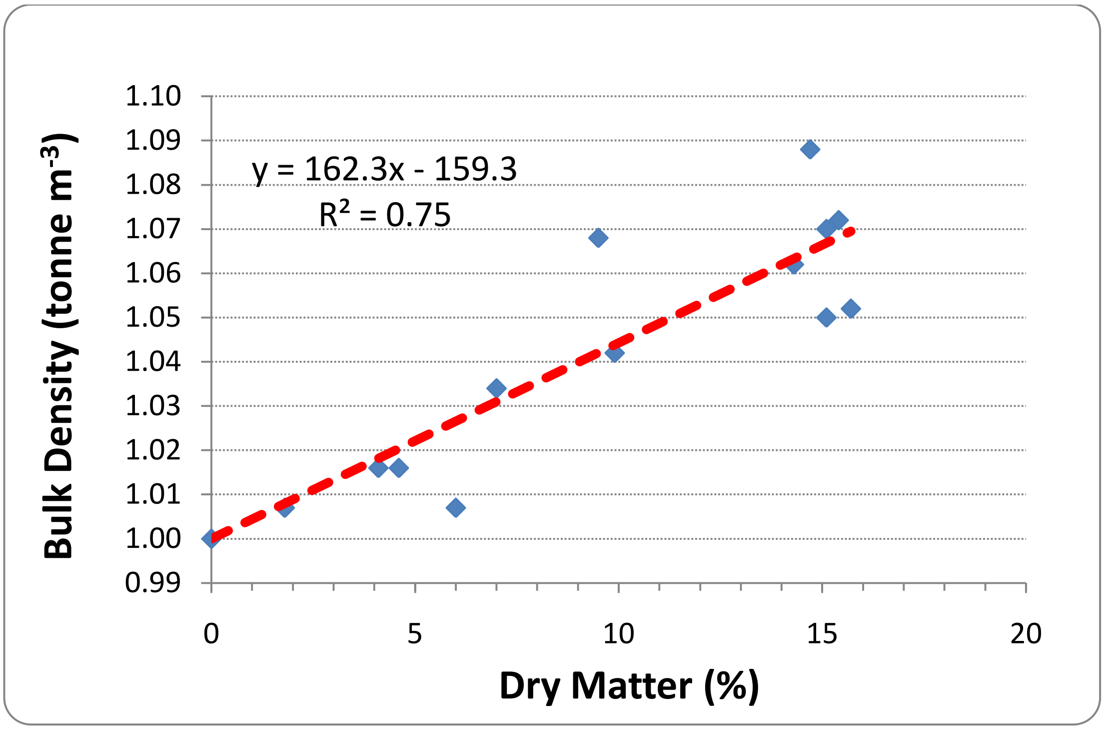

Figure 2: Bulk density and % DM data used for obtaining equation for liquids and slurries (*P* < 0.001).

3.4 Microbiological analysis

On a limited number of samples *Escherichia coli* (*E. coli*) bacterium populations were measured as an indication of faecal contamination. For each composite manure sample, *E. coli* were enumerated within the 24 hour period of sampling by using either a 5-tube most probable number (MPN) method or the Colilert-Quanti Tray system (Muirhead et al. 2004). Results are reported as MPN per 100g, the limit of detection is 100 *E. coli* per 100 g (ml).

4. System characterisation

4.1 Manures classification

Manures are generally characterised into effluents (i.e. FDE), slurries or solids depending on their solids content. Figure 3 provides an overview of the classification followed in this study. Effluents (0-5% DM) can be pumped as liquids, blockage problems are likely at solid contents above 7% DM. Slurries (5-15% DM) are semi-liquid and can be sprayed, not through irrigation pipes, but under pressure from a slurry tanker. Solid manures can be semi-solids or solid manure that cannot be pumped or sprayed. Solid manures are generally land applied via muck spreaders. A “grey area” exists between 15-20% DM solids content as there is just enough liquid that this manure can be sprayed but very heavy duty pumping equipment is required.

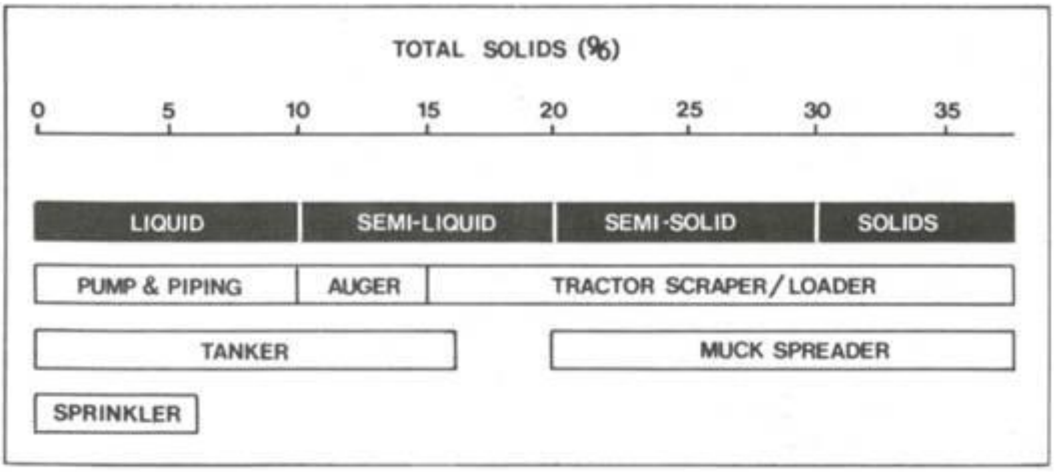

Figure 3: Guide to conveyance and application methods (source NZAEI, 1984)

4.1.1 Definitions and risk

- ***Farm dairy effluent (FDE)*** - *Animal excreta and water captured by the working surfaces associated with a farm dairy shed. Product capable of being pumped and sprayed with irrigation equipment* (0-5% DM).
- ***Slurry*** - *Excreta produced by livestock while in yard or building (plus additives such as water and animal feeds) that has the consistency that allows it to be pumped, augured or discharged by gravity (5-15% DM).*
- ***Solid manure*** - *Organic manure that can be stacked in a freestanding heap without slumping (> 15% DM)*

These definitions are adapted from Defra (2008a). Recommended dry mater percentages are guidelines that usually cover the behaviour of the effluent product. With regards to risk of direct nutrient losses at the time of application, we consider that slurry products should be treated as having a similar risk as FDE because the liquid behaviour means that contaminants can be conveyed in transported water via runoff and drainage. This will be further discussed in section 6. In comparison solid manures should be treated with regards to environmental risk as being similar to solid (but soluble in water) fertiliser products.

4.2 Classification of manure systems

4.2.1 HerdHomes® Shelters

The data from different HerdHomes® Shelters have been characterised into the three management options currently practiced by farmers. These are:

1. Liquid drained from bunker to obtain drier solids for applying via muck spreaders
2. Slurry, stirred liquid and solids with possibly extra liquid (from FDE system) added to obtain consistency suitable for spraying via slurry tanker
3. Solid manure for applying via muck spreaders

Results from laboratory analysis of TN, P, K and S for various HerdHomes® Shelter manures in the project are presented in Table 1. The ratio between N and K is also presented. Some data on HH manures, from a recently published manual (Pow et al, 2010), is available and these values have also been added for comparison. Results from Table 1 indicate that more variation in nutrient concentrations is likely when the manure has high liquid content. This can be seen when comparing the current data with the published data. All HerdHomes® Shelter manures are K-rich, especially the liquid fraction, and as the solids content increases the ratio of N:K gets closer to 1. The N:K ratio of solids also indicates that gaseous N losses are occurring through volatilisation. Table 2 presents the forms of N concentrations in manures. The % Mineral-N (plant availability) decreases as the manures increase from liquid to solids.

Table 1: Chemical composition of HerdHomes® Shelter manures: liquids and slurries (kg/m^3), solids (kg/t). Number of manure samples in brackets.

Manure	DM %	Total N	Total P	K	Total S	N:K ratio
Liquid						
Project (3)	1.8	0.92	0.13	4.13	0.11	0.2
Manual (10)	2.3	2.03	0.10	6.45	0.22	0.3
Slurry						
Project (12)	11.0	4.31	0.99	6.43	0.60	0.7
Manual (29)	9.0	3.43	0.73	5.72	0.42	0.6
Solids						
Project (12)	23.1	5.60	1.41	6.67	0.69	0.9
Manual (31)	19.0	5.70	1.40	7.40	1.00	0.8

Table 2: Forms of nitrogen and carbon content: liquids and slurries (kg/m^3), solids (kg/t) of HerdHomes® Shelter manures.

Manure	Mineral N [1]	Organic N	Total N	% Mineral N [2]	% Carbon	C/N ratio
Liquid	0.59	0.33	0.92	62	-	-
Slurry	1.67	2.64	4.31	39	3.65	8.5
Solids	1.56	4.04	5.60	28	9.68	13.9

[1] Mineral-N = Ammonium-N (NH_4^+-N) and nitrate (NO_3^--N). All NO_3-N concentrations were <0.0005%.

[2] % Mineral N = Mineral-N as proportion of the Total N.

4.2.2 HerdHomes® Dairyard

Manure from HerdHomes® Dairyard is treated in a similar fashion to that from HerdHomes® shelters except that greater emphasis is put into removing the liquid fraction from the manure to obtain a drier solids manure. As the Dairyard would be used every day during the lactation, strategies are employed to lessen the number of times that solids removal is required. The solid manure produced is applied via muck spreaders. The nutrient composition from Dairyard is higher than from HerdHomes® shelters due to the higher solids content (Table 3). The following box-plots (Figure 4) illustrate the overall variation in all the HerdHomes® Shelter manures. The manure solids had similar N and K concentrations (N:K ratio 0.97) but there was greater variation in K, possibly due to the effectiveness of the liquid drainage systems The largest variation in HerdHomes® Shelter solids and HerdHomes® Dairyard manures is in K content, while for slurries it is N.

Table 3: Chemical composition (kg/t) of HerdHomes® Dairyard manures.

Manure	DM	Total	Mineral	Total	K	Total	Org. C	C/N	%
	%	N	N	P		S	%	ratio	Min-N
Mean	27.5	7.37	1.03	1.97	7.59	0.97	9.7	13.9	14.2
Std. Dev (+)	7.5	2.85	0.51	0.84	4.23	0.48	1.9	3.8	5.8

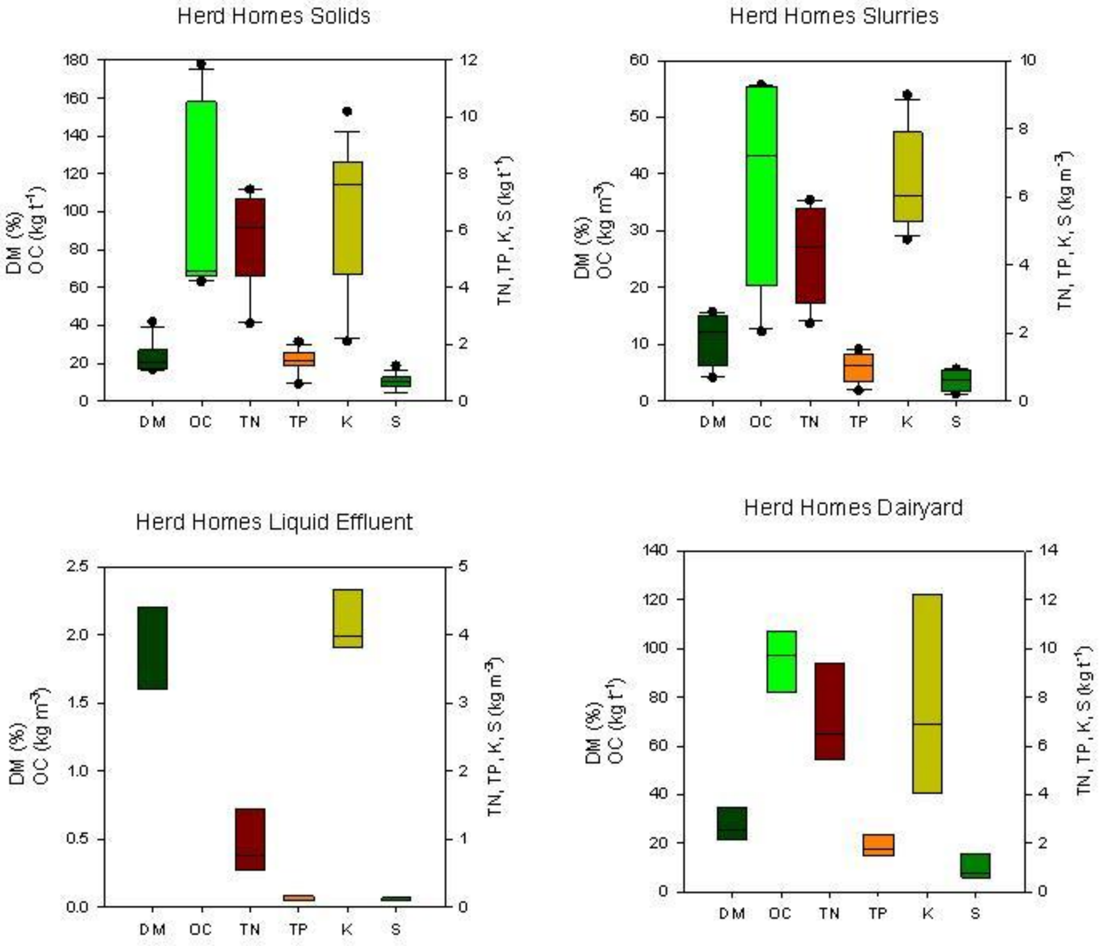

Figure 4: Box plots of HerdHomes® Shelter manures illustrating variation in concentrations.

4.2.3 Carbon-rich pads

A total of five sites were sampled that contained some form of carbon-based bedding/loafing areas. The variety of carbon-rich materials (sawdust, bark, wood chips and post peelings) used for stock bedding reflects local availability and price. Results from laboratory analysis are presented in Table 4. Note that the population base for each media type is very small. The bark/sawdust was from a covered barn, the post peelings were cleanings from a covered barn stockpiled in the open, and the wood chip was from an uncovered stand-off pad. Two carbon-rich materials (bark/sawdust and post-peelings) were K-rich, while the wood chip media was N-rich. Two samplings were carried out on pads used for calves. The first site had a covered calf pad with bark bedding. The second site used a carbon based pad for calving in the open. This pad has a bark base but topped with a layer of sawdust. Only the sawdust residue is removed at the end of calving. The calving litter is taken to paddocks by dump truck and then a tractor with a leveller is used to spread the material. Many factors are likely to influence the nutrient composition such as, stocking density, duration of usage (hours per day and days per month), length of storage, etc. The carbon content of fresh bedding media is normally around 50%, while Total N concentrations could be expected around 0.20%. Luo et al. (2004) reported C/N ratios of 233, 264, and 257 for pine bark, sawdust, and wood shavings, respectively. Wintering stock, with accompanying N-containing excreta, has decreased the C/N ratio on measured samples to between 17 and 28. However, mineral-N concentrations and % Mineral N indicate that plant availability would initially be low except for the post peelings based solids.

Table 4: Chemical composition (kg/t) of carbon-rich pads manures.

Manure	DM %	Total N	Mineral N	Total P	K	Total S	Org C %	C/N ratio	% Min-N
Bark/sawdust	30	4.49	0.07	1.46	8.65	0.81	-	-	2
Post peelings	38	4.57	1.15	1.49	12.37	-	7.6	17	26
Wood chip	30	3.50	0.02	0.84	1.04	-	9.7	28	1
Bark- covered	49	3.22.	0.08	0.87	1.91	0.42	21.2	70	25
Sawdust -open	39	2.87	0.06	0.73	2.40	0.33	16.7	58	2
Mean	**38**	**3.71**	**0.47**	**1.08**	**5.33**	**0.51**	**14.8**	**47**	**13**

4.2.4 Weeping walls

Four weeping wall systems were sampled in the project, one in the North Island and three in South Island. This form of effluent treatment originated in the southern part of the country but uptake of this technology has since spread to other regions. A summary of solids characteristics is presented in Table 5.

Table 5: Chemical composition (kg/t) of solids from weeping wall systems.

Site	DM %	Total N	Min N	Total P	K	Total S	Org. C %	C/N ratio	% Min-N
Manawatu	21	2.63	0.07	0.54	0.76	0.40	3.7	14.4	3
Southland 1	24	2.40	0.43	0.81	1.06	0.67	5.1	21.4	12
Southland 2	11	1.54	0.32	0.55	0.51	0.35	1.9	12.0	21
Otago	38	1.62	0.24	0.52	0.77	0.51	5.1	29.5	15
Mean	**23**	**2.44**	**0.25**	**0.61**	**0.87**	**0.54**	**5.0**	**20.5**	**11**

Results indicate that weeping wall solids have a relatively high N content, relative to K, as most of the K is mobilised into the liquid fraction and subsequent pond stored effluent. Note that this produces a very K-rich effluent for land application and hence effluent loading should be based on pasture K maintenance requirements. Some weeping wall systems are designed with parallel ponds so that the solids can build up in one, then the second pond is used while the first one is drying out, before switching again. Using this approach allows the first pond to dry somewhat, thereby reducing volume and amount of liquid that needs to be handled with the solids. Furthermore stored solids don’t have to be emptied so often during the season. Results show that the solids from the Southland 2 weeping wall were very fresh (much like cow faeces) whereas the solids from the Otago weeping wall had several months of drying time.

4.2.5 Separated solids

Mechanical

Four different sites were sampled that employed a form of mechanical solids separation. One site was in Southland and used a WSP screw press separator that produced an effluent with solid content averaging 35% DM (±5). The standard screen size of 0.5 mm, has been especially designed so that post separated effluent can pass through smaller diameter delivery systems such as fine nozzle sprinklers. The other three sites were in the southern North Island and used various forms of screw-press separators supplied from different companies. Bauer use a stainless steel screen size down to 0.25 mm so that effluent can be distributed by almost any type of spray irrigation system. FAN press screw separators have screen slot sizes ranging from 0.1-1.0 mm and can handle influents from 1-20% DM. The Yardmaster solids separator is used in a similar manner (spec’s not available), in that the post separated effluent was able to be pumped out through a low application rate small nozzle sprinkler irrigation system. A summary of solids characteristics is presented in Table 6.

Static screen

This one-off sample (Table 6) was considered to be a good representation of the solids that can be produced through static screens. Effluent flow and angle of screen can be adjusted to achieve a wetter or drier product. If considerably higher solids content was required (more like that from mechanical solid separators) then one or two rollers can be installed at the base of the screen to achieve the desired solids content.

Table 6: Chemical composition (kg/t) of solids from mechanical solid separators.

Solids separator	DM %	Total N	Min N	Total P	K	Total S	Org. C %	C/N ratio	% Min-N
WSP	35	6.16	0.04	1.07	2.34	0.77	11.7	19	1
Bauer	22	2.41	0.02	0.55	0.77	-	8.8	38	1
FAN	25	3.78	0.41	0.44	0.56	0.54	10.2	27	10
Yardmaster	22	2.68	0.01	0.50	0.78	-	9.2	34	1
Static screen	11	2.30	-	0.43	0.72				
Average	**25**	**3.59**	**0.15**	**0.59**	**1.00**	**0.63**	**10.0**	**30**	**4**

4.2.6 Scraped solids

European barn

At one Southland site, scraped solids were collected from a European-style wintering barn (the actual sample was from the barn's pond). Automatic scrapers remove solids from cow lanes within the wintering barn. Scrapings are removed to a collection pond for storage until soil conditions are suitable for land application. A summary of the solids characteristics is presented in Table 7.

Table 7: Chemical composition (kg/t) of from scraped wintering barn solids.

Scraped Solids	DM %	Total N	Min N	Total P	K	Total S	Org. C %	C/N ratio	% Min-N
Wintering barn	8.1	3.19	1.38	0.80	4.24	0.44	3.1	10	45

Feed pads

At two North Island sites scraped solids from feed pads were sampled. Both farms had large herds (600 and 800 cows) and used the feed pad on a daily basis. Solids are scraped to concrete lined bunkers for containment. Site one removes solids on a monthly basis throughout the year with the exception of spring during which they are removed weekly. At site two, solids are stored for lengthy periods (> 6 months). Site 2 solids contained higher amounts of spent feed. A summary of solids characteristics is presented in Table 8

Table 8: Chemical composition (kg/t) of scraped solids.

Solids separator	DM %	Total N	Min N	Total P	K	Total S	Org. C %	C/N ratio	% Min-N
Feed pad #1	19.5	5.33	0.49	1.14	7.38	0.73	6.8	13	9
Feed pad #2	29.7	6.28	0.27	1.37	7.87	0.89	9.2	15	4
Mean	**25.9**	**5.92**	**0.35**	**1.28**	**7.69**	**0.82**	**8.3**	**14**	**6**

4.2.7 System variability

Figure 5 illustrates the nutrient variability found in a range of dairy solids. Nutrient variability of carbon pads and separated solids is low for N, but high for K.

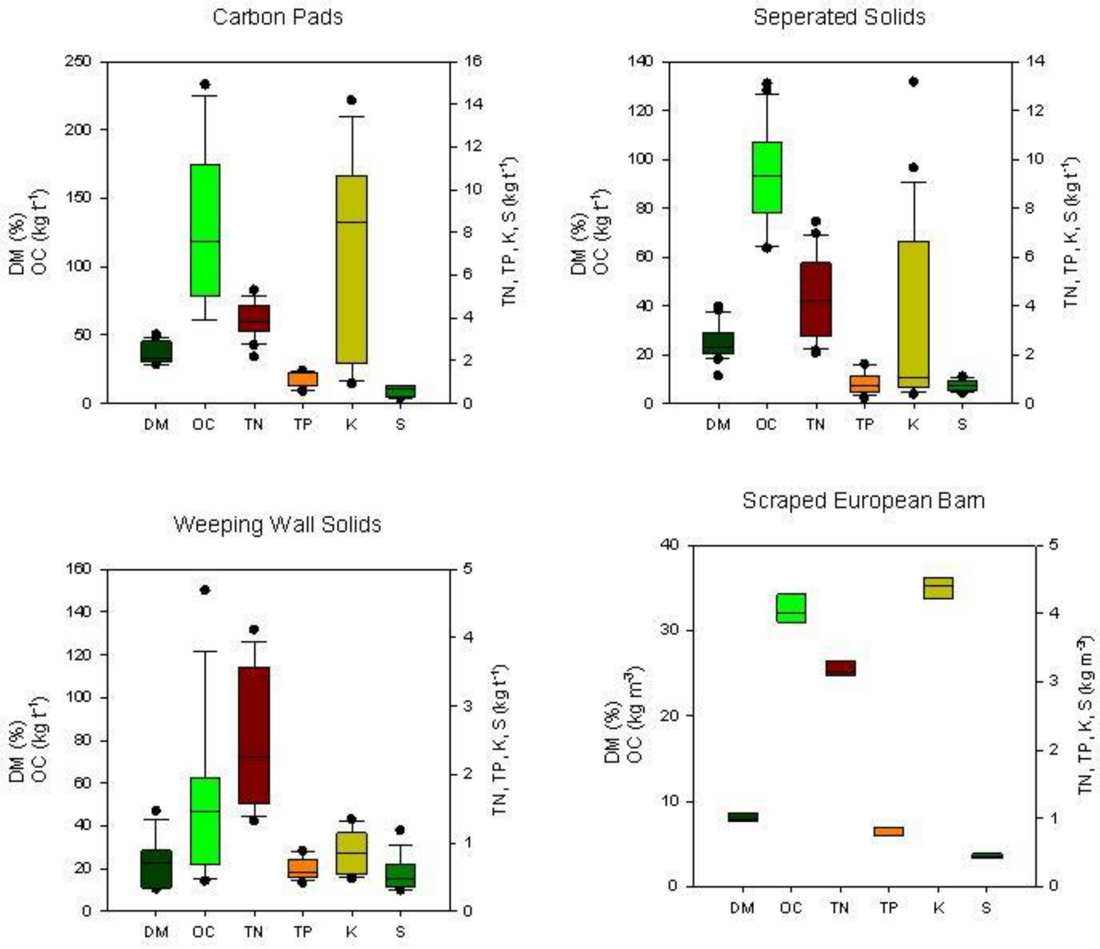

Figure 5: Box plots showing nutrient variability found in a range of dairy solids.

4.3 *Escherichia coli*

There is potential transmission of disease causing micro-organisms to grazing stock when manures are applied to land. Veterinarians have stated that as a precaution FDE should be spread thinly and not contain too many lumps, so that most micro-organisms are exposed to the sun and can be destroyed by ultra-violet radiation (Anon, 1987). Slurries, and certainly solid manures, will contain clumps when land applied. Hutchison (2004) showed that enteric pathogens decline in stored manure slurry, but Avery et al. (2005) found they are seldom completely eliminated. Infectious micro-organisms (pathogens) are only present from time to time whereas organisms that are always present in faeces can be measured as an indicator of disease causing risk (A.M. Donnison, pers. comm.). *E. coli* are widely used faecal indicator bacteria to assess the risk of pathogenic organisms.

E. coli were measured at 14 sites and populations ranged from 1.8 x 10^4 (HerdHomes® Shelter liquids) to 9.1 x 10^8 MPN per 100g (woodchips and calf litter). Table 9 presents the *E. coli* MPN detected and the typical loading to pasture when manures are applied at 3t DW/ha. Faecal microorganism numbers are highly variable; therefore, a difference of two orders is usually required to indicate an important difference between systems.

Table 9: *Escherichia coli* populations (MPN) found in manures during study.

Manure source	Average *E coli* concentration (MPN) per 100g or per 100ml	Applied in 3 t Dry Wt.
Wintering barn liquid effluent	2.42E+08	8.96E+13
Wintering barn solids	2.28E+06	2.22E+11
Woodchips + calf litter solids	9.10E+08	5.59E+13
Calving pad solids	1.42E+05	1.10E+10
Weeping wall solids	4.54E+05	3.60E+10
Weeping wall solids	2.41E+06	3.04E+11
Weeping wall liquids	4.99E+05	1.41E+11
Mechanical screw press solids	9.63E+08	8.23E+13
HerdHomes® Shelter solids	1.01E+07	1.51E+12
HerdHomes® Shelter solids	9.67E+04	1.91E+10
HerdHomes® Shelter solids with straw	3.99E+05	7.04E+10
HerdHomes® Shelter solids without straw	9.08E+05	1.64E+11
HerdHomes® Shelter slurry	4.43E+06	6.21E+11
HerdHomes® Shelter liquids	1.81E+04	3.01E+10

Few data are available in New Zealand on *E. coli* populations for dairy sludges and slurries. Luo et al (2005) found the average concentration of 2.4 x 10^9 100g wet weight of *E. coli* in faeces deposited on a Waikato stand-off pad. In comparison, from Table

45, at a manure application rate of 3 t DW/ha, the *E. coli* loadings ranged from 1.1 x 10^{10} to 9.0 x 10^{13} ha per 100g. The *E. coli* loading rates from a typical grazing event are in the range of 2.6 x 10^{9} to 1.1 x 10^{13} *E. coli* per ha (Muirhead, 2009). The *E. coli* loadings from an appropriate manure application loading are similar to a stock grazing event. The concentrations in the box plots (Figure 6) compare well with grazing concentrations of 1.7 x 10^{5} to 4.9 x 10^{8} *E. coli* per 100g.

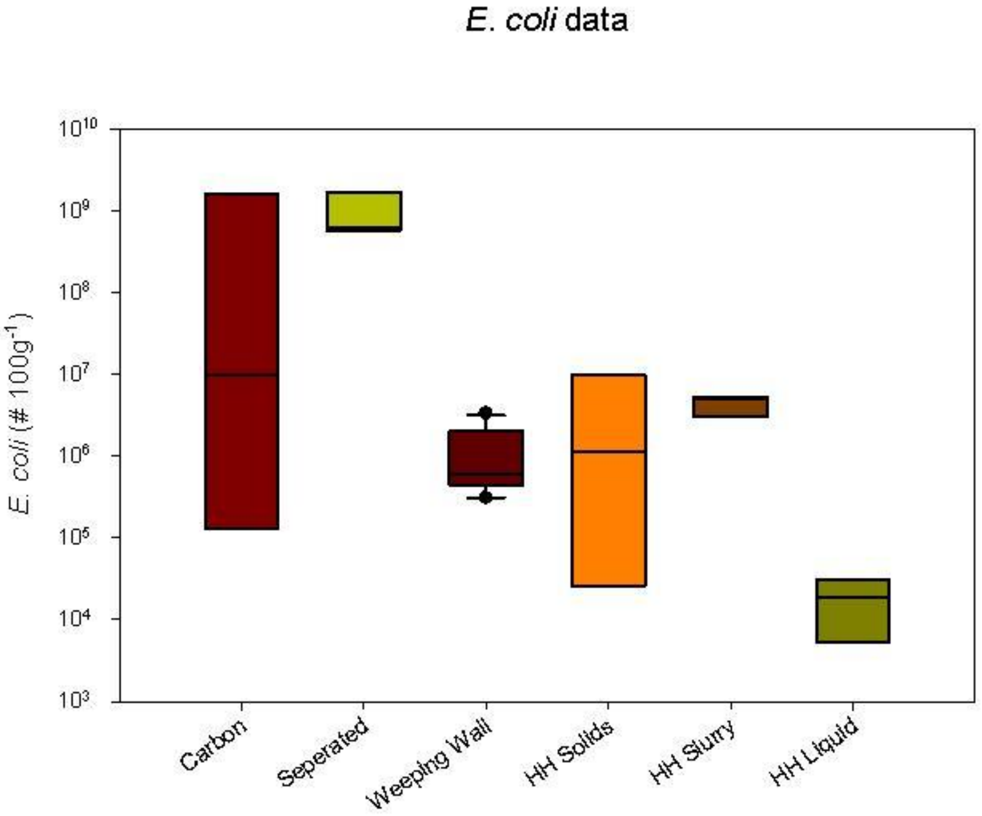

Figure 6: *E. coli* populations (MPN 100 g) in a range of dairy manures and slurries.

5. Considerations for best practice slurry and manure management

5.1 Characterisation process

As dairy farming has intensified over the past 10-15 years variation in farm practices between individual farms has widened. Previously with pasture-based dairying systems feed inputs were similar and therefore less variation in effluent concentrations could be expected. However this has changed markedly. Today, no two farms are alike, as feed importation is now so common and the variety of feeds available so great that the cows' diet, subsequent excreta, and form of effluent treatment is highly variable.

When a farmer is faced with the decision to land apply manures or slurries, there are three possible options available to determine the nutrient loading rates: 1) have the nutrient concentrations in the manures analysed and then adjust the loading rate accordingly, 2) use default values such as this report has produced, 3) use nutrient budgeting to derive an estimate of the nutrient loading for the proposed application area. Collecting a manure sample and forwarding it to an analytical laboratory has the advantage of obtaining the most accurate nutrient concentrations status. However it can be difficult to obtain a representative sample and there can be a time lag of approximately two weeks in waiting for the laboratory analysis and there is the laboratory processing costs (usually between $100-150) per sample.

Using default values is quick and easy plus there is no cost involved. The downside is that the values used may not be representative of a specific system. It is possible to have greater confidence in values from HerdHomes slurries and solids as there have now been 30-40 samples of each collected and analysed. Nutrient analysis of HerdHomes® Shelters liquids still show large variability (partly due to the small sample population) as do most of the other systems studied.

The third option could be to use the OVERSEER® nutrient budget to estimate the nutrient loading of manures and slurries. An estimate of the total amount applied could be obtained by multiplying the per hectare loading by the area (ha) of the effluent block. To clarify this, a comparison is needed against the laboratory analysis approach. Using data from an Otago dairy farm where the nutrient budget and chemical analysis were both available, some calculations can be made (Table 10). The depth of manure in the 60m x 7m bunker was approximately 0.9m.

Table 10: Estimate of nutrient loading to pasture via OVERSEER versus laboratory analysis x volume in manure bunker.

Nutrient loading approach	N	P	K	S	N:K
Nutrient budget					
Solids applied – kg/ha	127	43	58	23	2.2
Total loading (15 ha) – kg	1905	645	870	345	
Laboratory analysis					
Nutrient concentration - kg/t	5.0	1.4	4.2	1.0	1.2
In 378t - kg	1890	529	1588	378	

Table 10 illustrates that the estimated nutrient loading for N is remarkably close to measured values, P and S were also reasonably similar, while K was not such a close match. This comparison requires further investigation to validate the above findings. Comparing the N:K ratio indicates that the differences in nutrient loadings are substantial enough to deserve further investigation. The best approach may be a combination of using the nutrient budget and either default values or laboratory analysis.

5.2 Rapid testing

New Zealand dairy farmers do not usually test manures to determine potential nutrient resource. This reluctance may be partly due analytical laboratory cost involved and the time delay from sampling to receiving results (~ 10 days). In future, there is likely to be increasing quantities of European-type slurries (greater solids and nutrient content) generated from dairy farms which means the need for greater guidance to appropriately manage this nutrient resource.

In the UK/Europe a number of rapid test procedures (electrical conductivity, hydrometers, nitrogen meters and reflectometers) have been developed that may allow on-farm testing of effluent/manure products (Chambers, 1998). Rapid on-farm tests eliminate the time delay and cost when samples are shipped to a laboratory for testing. Currently there are more rapid on-farms tests for ammonium-N content of manures than for any other nutrient of interest. However, determining ammonium-N is of limited benefit in New Zealand where Regional Council requirements are based on Total N loadings. No quick test has been found satisfactory for the determination of P or K in dairy manures.

In New Zealand, Longhurst and Nicholson (2011) reported that conductivity meters could be used to provide a reliable estimate of N, P and K concentrations in dairy sump and pond effluents. However the solids content encountered in that study was below 5% DM and may not be applicable to manures and slurries.

Key criteria that must be met for widespread adoption of rapid on-farm testing are:

- To ensure accuracy, calibration curves must be region-and farm-type specific.
- To ensure accuracy, the sampling technique must be correct.
- To ensure farmer uptake of technology the systems must be ‘user friendly’, simple and affordable.

Future development may move towards an on-farm system able to test more than one substance (i.e. manure, feedstuffs, soil) in a ‘user friendly’, time efficient and accurate method using Near-infrared spectroscopy (NIRS).

5.3 Delivery systems

In this study three different spreading systems were used for applying the manures and slurries to land: slurry tankers, muck spreaders and a tip truck approach with a tractor fitted back blade for spreading. Slurry tankers usually rely on a vacuum pump to fill slurry tankers and pump slurry effluent out over an inclined splash plate to spread its footprint stretching usually greater than 10m either side of the passing vehicle. It is important that the splash plate is correctly set up in order to spread the associated spray swath evenly. Slurry tankers can manage effluents that have DM content up to 12% and behave in a liquid manner. However at the higher end of this scale the slurry may need to be thoroughly stirred and homogenised prior to removal from storage (Chambers et al. 2007b). Muck spreaders are designed to handle effluents that cannot typically be pumped. Side spreaders typically have a cylindrical body with a PTO driven shaft that runs along its length throwing the manure out the side of the spreader. In comparison a rear discharge spreader has a moving floor such as spinning disks or vertical and horizontal beaters that move the product towards the back of the spreader. Some muck spreaders are multipurpose as they can handle liquid slurries and dryer manures through a side discharge where by an auger and closing gate forces effluent onto a spinning impeller. Of these three options, Chambers et al. (2007b) suggests that rear discharge spreaders have a more even distribution uniformity and lateral precision compared to side discharge spreaders. The same observation was also made in New Zealand by Pow et al. (2010).

The New Zealand dairy industry has recently developed and released a design code of practice for farm dairy effluent (DairyNZ 2011). This document was largely focussed upon the typical liquid effluent products (i.e. those that can be pumped) that are produced on dairy farms. Aside from the pumping and engineering specifications, which are clearly different for solid effluent management, much of the advice related to nutrient management and product storage is relevant to slurry and manure application. One aspect of the code relates to the uniformity of distribution from effluent application systems. In order to encourage acceptable uniformity of application of dairy effluents the code suggests infrastructure should be able to meet a minimum uniformity requirement based upon its distribution uniformity. In particular it suggests an upper quartile distribution uniformity (DU_{uq}) of < 1.25 should be achieved for all liquid effluent application systems (DairyNZ 2011). It then suggests that effluent solids should be treated as if it were a solid fertiliser product. Where sufficient data points were gathered we calculated the DU_{uq} for each case study. This data is presented for each case study and is summarised in Figure 7. In summary, slurry products were more uniformly applied than solids/manures. This is logical considering they behave as a liquid whilst solids come with a wide range of aggregate sizes and different ballistic properties if thrown into the air. Whilst slurry tankers and rain guns had the best distribution uniformity, their DU_{uq} of 1.6 was considerably greater than the value of 1.25 recommended as a design standard for liquid effluent products in the FDE code of practice (DairyNZ 2011). The next best distribution was surprisingly from the spreading of solids/manures by tipping the product onto the ground and spreading it around using a tractor which with a DU_{uq} of 1.9 was lower than either a muck spreader with side discharge (DU_{uq} of 2.1) or a muck spreader with a rear discharge (DU_{uq} of 2.3). The poor uniformity of the different distribution systems is disappointing; however it does need to be kept in context with the way that cattle dung and urine patches are currently distributed around grazed paddocks. Of greater importance, than uniformity, with regards to potential environmental effects is being able to manage the mean application loading rate of nutrients while taking into account the potential outlier values.

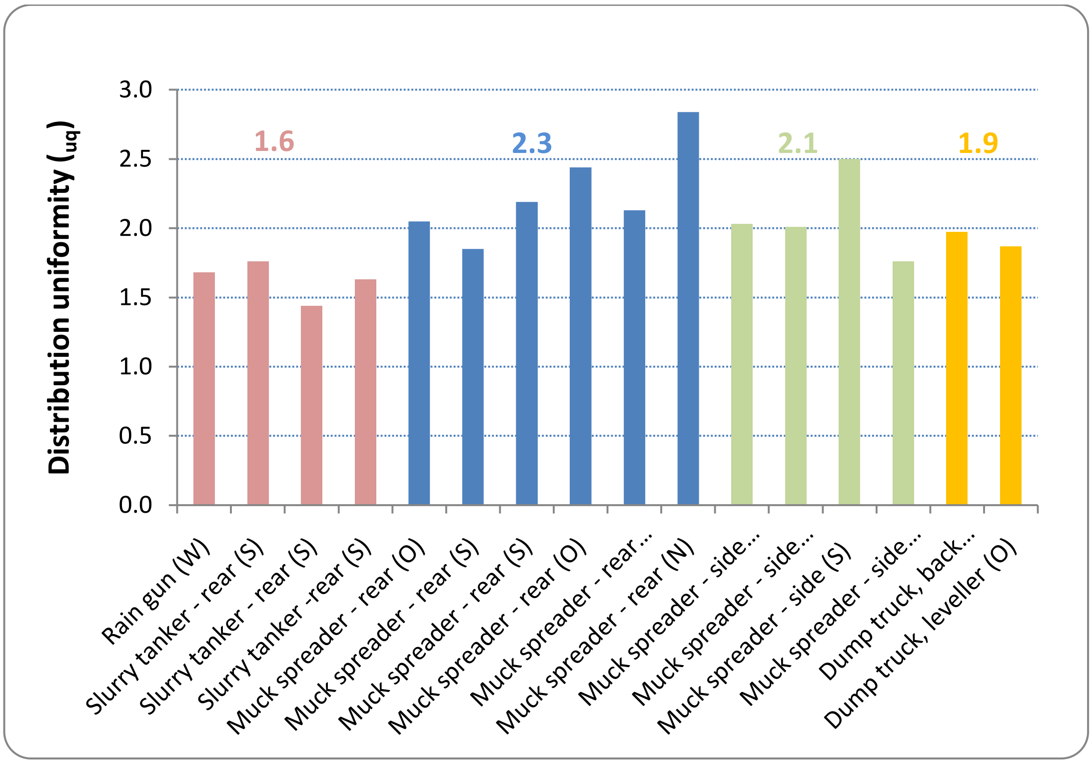

Figure 7: Upper quartile distribution of uniformity for different spreading systems, with the average shown for four generalised groupings.

In order to mitigate the effects of NH_3-N gaseous losses from land applied slurry, considerable European research and development has been conducted on trailing shoe technology or soil injection systems (Misselbrook et al. 2000, Smith et al. 2008, Webb et al. 2010). Trailing shoe systems are either attached to slurry tankers instead of splash plates or directly to a tractor pulling an umbilical hose from the storage facility (Chambers et al. 2007b). Trailing shoe apparatus band spread the slurry on the soil surface but below the pasture sward and therefore avoids pasture contamination while providing greater protection from volatilisation losses (Smith et al. 2000 & 2008, Laws et al. 2002). Furthermore the spread pattern and application loading rate has been shown to be considerably more uniform using trailing shoe technology as opposed to surface broadcast methods. Direct injection into the ground can achieve the same outcomes as trailing shoe technology but is less preferred in some cases as it requires greater energy inputs (tractor horsepower) to pull the injection apparatus and the small bout widths mean that labour inputs are also higher. Furthermore, injection systems are best suited to fine to medium textured silt or loamy soils as opposed to coarse textured stony soils or very fine textured dense clay soils (Smith et al. 2000). However in some countries, such as the Netherlands where there are suitable soil types, injection of effluents is compulsory. The implications of different application methods on agronomic and environmental performance will be discussed further in section 7.5 and 7.6.

5.4 Nitrogen loading rates

Optimum nutrient loading rates will vary dependent upon land use. In New Zealand regulatory authorities tend to use a maximum permissible N loading rate of either 150 or 200 kg N/ha/yr for N loading from dairy effluents. Dairy slurry and manure applications therefore come under this permissible N loading rate. In New Zealand there has been considerable research related to the relationship between N loading rate and N leaching for our pastoral based farming systems. The extent of N leaching is a product of the surplus of mineral N in soil (largely dependent on N inputs), the mobility and retention of N forms in soil (affected by soil properties), and the level of drainage (determined mainly by rainfall). Figure 8 suggests that nitrate-N loss increases considerably when N fertiliser inputs exceed 150 to 200 kg N/ha/year. Ideally a nutrient budget should be prepared for individual locations where specific climate and soil type variables can be considered and used to derive better estimates of nitrate-N concentrations in drainage water.

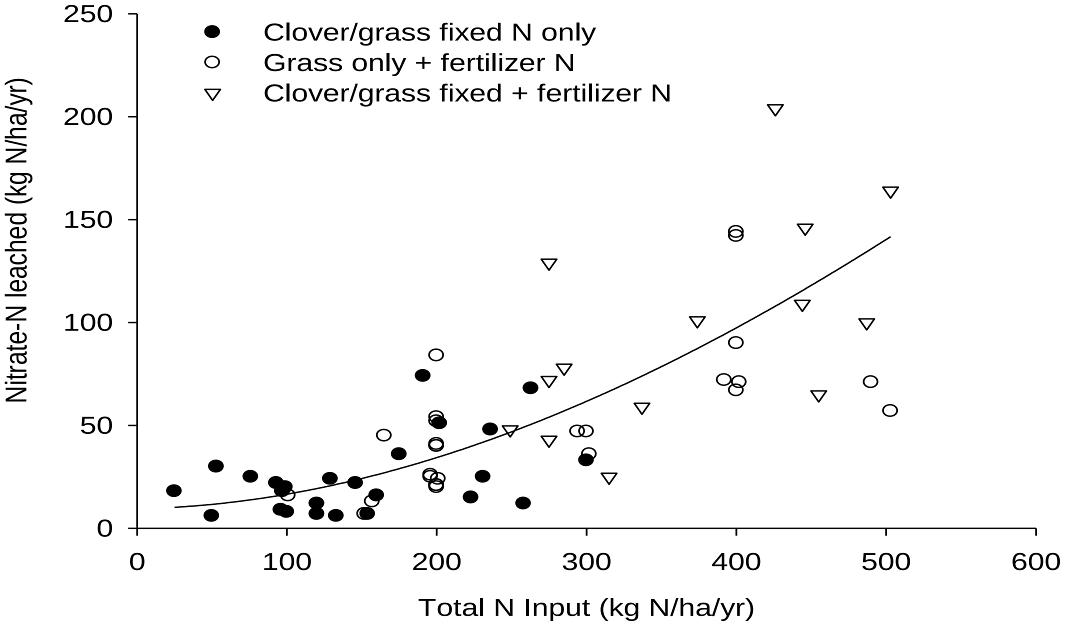

Figure 8: Nitrate leaching from grazed pasture systems as affected by total N input. Data are a summary of studies in Europe and NZ (from Ledgard et al., 2009).

Cropping scenarios (or cut & carry silage operations) are different however to long term pastoral situations. Cropped areas do not have the added complication of nutrient return via urine patches while some high yielding crops can utilise greater N than a pasture would. Scholefield et al. (1991) demonstrated the difference in relationship between fertiliser N use and N leaching for a grazed and cut and carry scenarios (Figure 8). In New Zealand Johnstone et al. (2010) reported that maize, receiving a single load of 221 kg N/ha just prior to sowing as FDE has resulted in no increased N leaching loss.

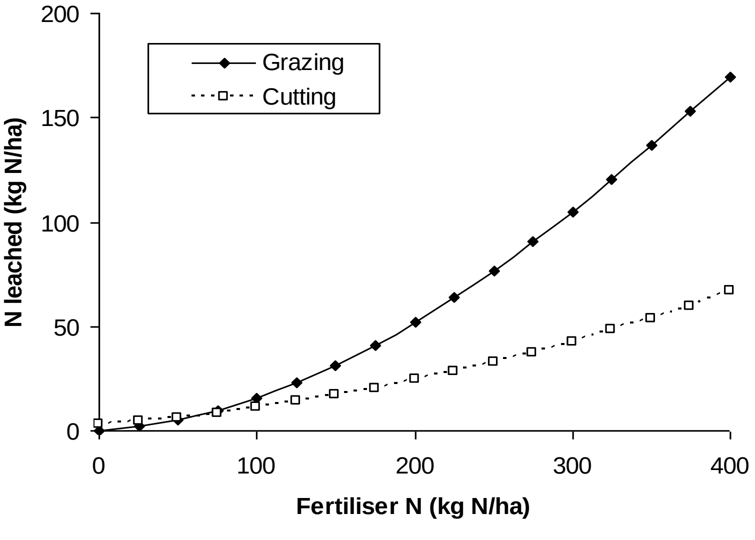

Figure 9: NCYCLE model predictions (Scholefield et al., 1991) of the amount of N leached from grassland with increasing fertiliser input under beef grazing compared with a cutting management (sand soil, long-term grassland, sward age 4 - 6 years).

Determining N use (from either fertiliser or effluents) in crops is largely dependent upon the yield potential but influenced by factors such as soil moisture, soil type, paddock history and crop management (FertResearch 2009). Of great importance is the background fertility status and so a deep soil mineral N test should be conducted to determine expected N supply that is present in soils.. Paddocks under long term cropping are most likely to have a low soil mineral N status (< 50 kg N/ha) and would therefore require the greatest N input. For example, FertResearch (2009) suggests that a high N use crop such as maize silage with a high yield potential (>22 t DM/ha) would require a maximum N loading rate of 245 kg N/ha/yr when the background deep mineral N test was low (< 50 kg N/ha). In comparison, a soil with a high background deep mineral N test > 200 kg N/ha) would only require between 0 and 80 kg/ha/yr.

A more targeted approach to determining N loading requirement such as described above would seem more suitable than recommending a blanket permissible application depth such as the 7 mm rule utilised by some New Zealand regulatory authorities. In the case studies presented, only one example had an average application depth approaching the 7 mm threshold at 6.4 mm. However this slurry was very liquid at only 1.7% DM and applied through a rain gun. The low concentration of N (0.62 kg N/ha) meant that the average N loading was only 40 kg N/ha.

In the UK the maximum permissible N loading rate from effluent N (manure or slurry) is 250 kg N/ha/yr under the nitrate vulnerable zones action programme (Smith et al. 2008). However, Chambers et al. (2007b) suggests that best practice would restrict crop N inputs to a maximum 200 kg N/ha/yr based on an optimum response. Furthermore they recommend that effluent inputs are strategically used in combination with mineral N inputs whereby the first 100 kg of N applied was from organic sources and the remaining N input (up to 100 kg N/ha/yr) was applied with fertiliser N depending upon specific crop requirements.

From the 17 case studies presented in section 4 where effluent application volumes/weights were determined, the mean N loading rate was 79 kg N/ha with a range from 13 to 221 kg N/ha. Only the application of 221 kg N/ha from case study 3 was greater than 150 kg N/ha. In this case the fate of the manure application was a high nutrient use crop in the form of maize silage. Therefore the data collected from the case studies suggests that the slurry and manure application volumes/weights were generally well managed with regards to their N loading rate.

It is important to note that the nutrient loading rate may not always be set based on reaching N loading limits. In liquid waste streams K is typically the limiting nutrient whereby plant requirement is first reached. K limit may also be reached in fully contained slurry systems prior to N reaching agronomic requirements. However separated solids will be relatively lower in K because it is very mobile and will likely be found in greater proportion in the liquid fraction. With regards to P, however, it is conceivable that P agronomic limits could also be reached in separated solids and large portions of P are bound to the solid fraction. Based on the case studies presented this does not appear to be the case unless the soils receiving the solids had very high Olsen P that required small or no P inputs in order to decrease P fertility.

5.5 Environmental considerations

5.5.1 Water quality

The application of slurries and manures to land can pose two different forms of environmental risk: nitrate leaching or overland flow carrying nutrients and faecal microorganisms. Nitrate leaching associated with land application of manures and slurries is a result of N inputs into the whole farm system. Where animal effluents are applied to crops or cut and carry farm systems then effluent N will be the predominant source of N input. European research has demonstrated that the risk of N leaching from applied animal effluents is strongly related to timing (i.e. month of application). Figure 10 demonstrates that slurry applied in autumn (September, October and November in the Northern Hemisphere) poses the largest nitrate leaching risk as a proportion of total N input. This suggests that N utilisation from the applied slurry/manure in autumn is lower because of the relationship between excess rainfall in winter and the volume of drainage passing through the soil. The research reported by Smith et al. 2008 suggests that spring applications of slurry/manure will result in the smallest proportional loss as nitrate because of the large number of growing days before the next drainage season. It’s for the same reason that effluents applied in late winter (i.e. January in Europe) have also shown to result in a small loss of nitrate N as there is only limited opportunity for mineralisation and nitrification processes to take place before the drainage season ends and hence the total drainage flux subsequent to application is limited compared to the cumulative drainage total.

Another driver of nitrate leaching risk from slurry/manure application relates to the N content and form of the effluent applied. Figure 10 also demonstrates the decreased risk for nitrate leaching from applying farm yard manure (scraped barn floor manure) compared to slurry. This is because farm yard manure has a much larger proportion of inorganic N than slurry which has greater mineral N contents. Farm yard manure also tends to contain significant straw inputs that add a large carbon content and result in a relatively high C:N ratio product which will encourage net immobilisation of nitrate when applied to the soil (Chambers et al 2007b). In addition, stored liquids and slurries tend to have a high mineral N content (in the form of NH_4) at the time of application which provides a source of N rapidly available to plants but, also leaching, if converted to nitrate-N subsequent to land application (Chambers et al 2007b). In comparison more solid manure products are reported to have a much lower mineral N content and therefore have to rely upon the mineralisation of the organic N from the manure before having a source of N that is prone to leaching. This method of more slowly supplying plants with a source of mineral N further decreases the risk of N leaching (compared to slurry) especially from land application events in winter. Data collected during this programme suggests that carbon pad manures and mechanically separated solids contain a product that has a low mineral N content (< 15%) and high C:N ratio (>30) that would be more suitable for land application before the onset of the active growing season in spring. In comparison, the slurry product derived from a scraped barn system had a mineral N content of 45% and a C:N ratio of 10.

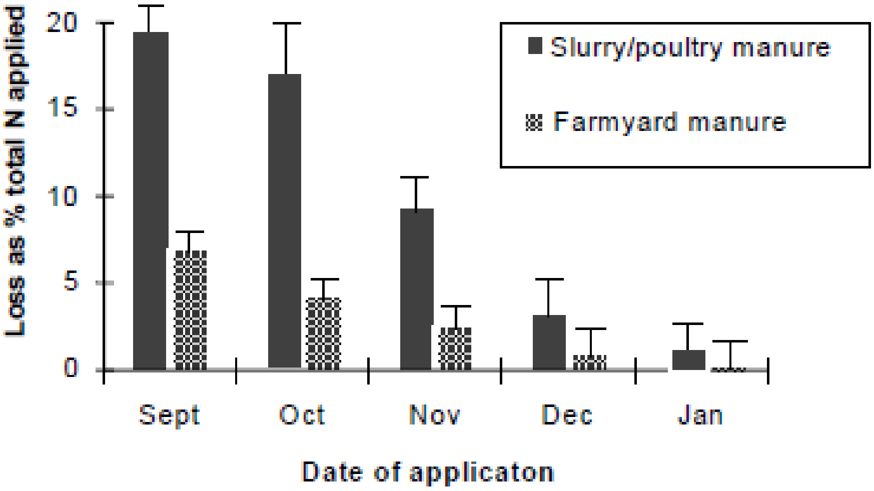

Figure 10: Nitrate leaching losses following application of slurry and farm yard manure to an arable free draining sandy shallow soil. Sourced from Smith et al. (2008).

The land application of slurries and manure are also prone to losses of contaminates that affect water quality as a result of surface runoff. For slurry products that behave as liquid this can be a result of heavy application during inappropriate soil conditions (high soil moisture content) and from the subsequent movement of contaminants in surface runoff developed by excess rainfall conditions. In comparison, more solid manure products will not runoff during application but are still prone to losses from rainfall induced overland flow conditions. The main contaminants of concern are faecal microorganisms, P and NH_4^+-N (Smith et al. 2001 a & b). The risk of surface runoff losses are related to the timing of application, soil and topography, volume of applied effluent and the form and content of effluent applied (Smith et al. 2008).

Research has shown that NH_4 and P loss in surface runoff is strongly related to application method and timing with respect to rainfall. Smith et al. (2001 a & b) reported that increasing the time between application and subsequent rainfall will considerably decrease the risk of contaminant losses. A minimum time period of 48 hours between application and runoff is required in order to avoid large runoff losses. However a 10 day period is recommended by Smith et al. 2008 in order to adequately mitigate the risk. Withers and Bailey (2003) reported that water soluble P would remain present from a 50m^3/ha application of slurry up till 50-60 days post application. They also reported that there was no remaining evidence of surface applied slurry by the 85 day mark. Smith et al. (2001 a & b) also reported that increasing the nutrient loading rate of a single application increases the risk of loss in subsequent surface runoff. They recommend that applications should be limited to a maximum of 50 m^3/ha of slurry or 3 t/ha of solids content on a dry weight basis as in accordance with UK good agricultural practice guidelines'. For example, a 6% DM slurry with an N content of 3 kg/m^3 would provide an N loading of 150 kg N/ha. Applying 3 t/ha of solids would also result in an application of 50m^3 of a slurry that had a 6% DM content. However we feel that such a recommended limit is not suitable for more dilute effluents (i.e. < 2% DM) as the nutrient and solids loading would be considerably reduced and greater proportion of the effluent would infiltrate into the soil. The onset of surface runoff conditions is related to conditions such as soil moisture, topography and surface infiltration. However Smith et al. (2001 a & b) also reported that heavy applications of slurry/solids (> recommended application rates) may also result in the clogging of soil surface pores and hence decrease the surface infiltration rate of a soil leading to increased surface runoff risk. In the case studies presented above slurry was sometimes sprayed onto steep sideling's. It would appear that this would come with a high risk of subsequent contaminant losses in surface runoff following rainfall events.

The form of N and P applied in slurry and manures will also influence the risk of contaminant losses. Smith et al. (2008) concluded that slurry containing a high mineral P content has a greater risk of N loss in subsequent rainfall driven overland flow events than a manure with a high organic N content. Similarly, slurry with a proportion of bio-available P (DRP) will have a much greater risk of subsequent P runoff loss than applied manures unless prolonged saturation excess conditions are prevalent when the P form bound to solid content may become more mobile.

In addition to landscapes prone to surface runoff generation, the application of slurry to land has been proven troublesome when applied to soils with a high clay content due to their preferential flow pathways and also to land that has been mole and pipe drained (Hodgkinson et al. 2002, Smith et al. 2008). As slurry (< 15% DM) behaves as a liquid, this finding is consistent with the research conducted in New Zealand on liquid effluent (FDE) from yard washing (Houlbrooke and Monaghan 2010). To adequately mitigate this risk, application depth (volume) needs to be managed and applied when a suitable soil water deficit exists, in order to prevent direct losses at the time of application. In addition to timing, form of effluent and soil and landscape risk, the method of application will also influence contaminant loss risk. Withers and Baily (2003) compared a surface application of 50 m^3/ha slurry (supplying c. 30 kg P/ha) with a treatment that was immediately incorporated into the soil by cultivation. It was reported that the surface application lost c. 23% of total P applied in the first rainfall induced surface runoff event immediately after application, most of which was in the soluble P form. This single event represented 60% of the total P loss for the year. Incorporating surface applied slurry decreased the volume of overland flow generated by 50% and the P loss by 60

With regards to mitigating the risk N leaching from land application of slurries and manures, then applications from mid winter to midsummer are considered lowest risk. However losses of P & N in surface runoff and from slurry applied to mole and pipe drained soils or soils with preferential flow are greatest during periods of high soil moisture and rainfall, typically found in the winter and early spring period. It would therefore appear that timing one-off applications for late spring, once suitable soil water deficits have developed, would be optimal for minimising the environmental risk of land applied slurries and manures. Late spring also matches agronomic considerations regarding the timing of crop establishment where appropriate and the period of active plant growth (see section 7.6 below) whilst avoiding the height of summer when potential volatilisation losses of N would be greatest (see section 7.5.2 below).

Manures and slurries also represent a risk of faecal contamination to water (Oliver et al. 2007). In section 6.3 we showed that the loading of *E. coli* onto land, at the recommended loading rates, would generate similar contamination rates to typical rotational grazing events. However, the risk of runoff from the manures and slurries may be higher than a grazing event due to the increased surface area of manures (Oliver et al. 2007; Muirhead and Littlejohn 2009). Mitigation options to reduce the risk of runoff losses of *E. coli* are (a) storage prior to land application to allow time for microbial die-off and (b) timing of application to avoid runoff events soon after application to land (Meals and Braun 2006).

5.5.2 Gaseous emissions

Storage and application of dairy slurries and manures can result in gaseous losses of ammonia, nitrous oxide and methane. During anaerobic breakdown of organic wastes, biological degradation in the absence of oxygen will result in the production of methane (CH_4), a greenhouse gas with a global warming potential of 21 CO_2-equivalents. Its production is influenced by the amount of degradable organic matter in the effluent termed biological oxygen demand (BOD). There appears to be little known about methane losses during land application of slurries and manures. Nitrous oxide (N_2O) is also a greenhouse gas, with a global warming potential of 298 CO_2-equivalents. Nitrous oxide emissions from storage of FDE, manure and slurry are not large because of the limited nitrification activity. Denitrification under anaerobic conditions will see much of the N reduced to N_2, with only a small amount being emitted as N_2O. During 5 months' slurry storage, N_2O emissions are estimated to be 0.04% of the total N (Luo and Longhurst, 2008). Increased emissions are expected from manure, with losses a magnitude greater, at 0.4% of the total N for a 5 month storage period (Luo and Longhurst, 2008; Monaghan et al. 2009).

In New Zealand the gaseous loss of ammoniacal N, as NH_3, is not considered an environmental problem. However in Europe, volatilization of NH_3 into the atmosphere contributes to the acidification of potentially sensitive habitats when ammonia combines with sulphate and nitrate in acid cloud droplets. This process has been demonstrated to be slowly changing the botanical composition of fragile ecosystems such as heath lands. Despite the lack of environmental pressure, volatilisation of N from effluent slurries and manures (either during storage or application) represents a large potential loss of N resource for the farmer. NH_3 loss during storage is dependent on effluent DM and duration of storage, as well as storage temperature. Losses during a 5-month storage period from a manure storage bunker are estimated to be 8-13% of the total N. Losses from slurry storage for the same duration is estimated to be 16-26% of the total N stored (Luo and Longhurst, 2008; Monaghan et al. 2009).

Considerable NH_3 volatilisation can occur when dairy manures and slurries are applied to land. Emission factors for NH_3 are typically presented as a percentage of the total ammoniacal-N (TAN) applied. In the UK, emission values increased from 15 to 59% as the slurry dry matter increases (Misselbrook et al. 2000). During the warmest months, a value of 60% is suggested, as volatilisation from slurries is highest during summer when temperature and solar radiation are greatest. Gaseous losses from solid manures are estimated to be 76% of the TAN applied (Misselbrook et al. 2000). Furthermore, volatilisation from slurries applied during the morning or evening were generally half that observed when applied at mid-day (Sommer and Olesen, 1991).

Method of application also influences volatilisation loss during application of liquid effluents and manures. Droplets formed by spray application of liquid effluents increases the total surface area between effluent and atmosphere resulting in greater volatilisation. Considerable research has been undertaken in the Europe and the United States in order to identify mitigation techniques for decreasing ammonia losses following land application of slurry. New technologies such as shallow injection, banding and trailing shoes reduce the exposed surface area of slurry, while incorporation of slurry and manure into soil removes surface exposure of the effluent thereby reducing both NH_3 losses and odours (Chambers et al. 2007b). Misselbrook et al. (2002) demonstrated a 73, 57 and 26% decrease in NH_3 loss for shallow injection, trailing shoe and surface band spreading techniques, respectively, compared to a surface broadcast application. These losses were equivalent to 13, 12 and 35% of the TAN supplied as slurry for shallow injection, trailing shoe and surface band spreading techniques, respectively. An alternative method for decreasing volatilisation loss is the rapid incorporation of slurries and manures immediately following surface broadcast application. Webb et al. (2010) reported that 90% of potential loss could be mitigated by immediately cultivating the paddock whilst a delay of only 4-6 hours proceeding application would result in considerable losses. From a practical point of view, incorporation is only possible where pasture is being renewed or where slurries and manures are being applied to cropland.

5.6 Agronomic considerations

It is generally accepted that slurry and manure management practices that result in low nutrient loss (water or gaseous) will result in the greatest nutrient use efficiency and agronomic benefit (Smith et al. 2008). As described in section 7.4 above, applying slurries and manures at nutrient loading rates appropriate for plant requirements will result in achieving optimum plant yield. To achieve the greatest nutrient use efficiency, from applied animal effluents, will require soil testing, nutrient budgeting and an understanding of the NPK nutrient loading rate for the given volume applied. Nutrient loading should be based upon which ever macronutrient is in greatest demand compared to plant requirement. Once this limiting nutrient is achieved from a design application volume then any remaining shortfall from other macronutrients should be met using supplemental fertiliser. For example in many liquid (i.e. FDE) or slurry based effluents the proportion of K is likely to be much greater than crop requirements compared to N and P input and therefore application volume should be designed around achieving optimum K input. However in systems that have undergone some form of solid separation the ratio of N to K is considerably increased as K is very mobile and a large proportion will be transported with the liquid fraction (See section 6.2). In these circumstances the optimum nutrient loading rate will more likely be designed around N loading rate, or possibly P, if the receiving soil is already at, or, in excess of optimum soil fertility (Olsen P).

In New Zealand there is very little research related to the agronomic performance of pasture or crops resulting from the application of slurries or manures. A study reported by Cameron et al. (1996), based in Canterbury, demonstrated that annual pasture yield following a large dairy pond sludge application (300 kg N/ha/yr) increased 40% above a control treatment with no additional nutrient input. An important knowledge gap for New Zealand farmers relates to the fate of organic N applied to soil (as effluent) with regards to the timing and release of N in mineral form available for plant uptake. International literature suggests this will be dependent upon a number of factors such as time of application, soil temperature, soil moisture content, microbial activity, plant uptake soil C:N ratio, loading rate applied and total mineral N content vs. organic N content (Smith et al 2008). A recent trial investigating the maize utilisation of FDE by Wallace et al. (2011) confirmed that effluent could be used as a replacement for bagged fertiliser without a decrease in crop yield. However, the exact fate and release of applied N was unknown. In the UK, a farmer decision tool called MANNER has been developed from historical research that can predict the fertiliser value of N of applied slurries and manures taking into account the type of effluent, N content and form, soil type, application timing and technique. In order to provide the fertiliser N value it predicts gaseous and leaching losses and N mineralisation rates.

As described in section 7.5.2 above, the volatilisation of NH_3following land application can considerably decrease the size of the N resource available for plant uptake and therefore have a large effect on nutrient use efficiency and yield potential. Rapid incorporation is one method for mitigating the potential effect of gaseous losses. However this is not practical if effluents are being applied to grassland. As also described in section 7.5.2, application technology can be used to mitigate the effect of NH_3 volatilisation. Trailing shoe technology is now considered and promoted as a best management technique for applying slurry to pasture land uses throughout the United Kingdom and Ireland. Trailing shoe technology also has an advantage of considerably improving distribution uniformity compared to the uneven distribution under surface broadcasting with splash plates (Yagüe and Quílez, 2010). Poor distribution uniformity has been reported to result in poor utilisation of nutrients by crops and a subsequent increase in NH_3 volatilisation (Thompson et al. 1990). Furthermore, trailing shoe technology has been shown to increase pasture palatability and pasture quality as slurry is spread as a band to grasslands under the pasture sward avoiding any pasture taint associated with surface broadcasting (Laws and Pain 2002). Smith et al. (2008) reported a 5-20% scorching-induced decrease in grass growth following surface application and recommended a maximum application loading of 50-65 m^3/ha of approx. 6% DM slurry. This recommendation also lines up with recommended maximum application loading rates based on environmental management considerations. In summary, considering the New Zealand dairy industries pastoral land use and tight grazing rotations, in addition to traditionally wet spring periods and hot summer conditions, it would appear that best practice for land applying winter generated slurry in New Zealand would be a late spring application using trailing shoe technology.

5.7 System comparison

The choice of whether a farmer should remove and apply manures as slurry or solids has to be assessed on a case by case basis as no two farm systems are the same. Preference for use of one approach will depend largely on the individual farmer and what farm machinery is currently available for appropriate land application. Smith at al. (2008) did however acknowledge that farmers found it easier to calculate loadings based on know slurry tanker volumes than based on weights for solid spreaders. In situations where cows are partially housed for extended periods the focus is likely to be on removing liquid to produce drier solid manures. Removing liquid reduces volume therefore increasing the storage capacity of the system. The farmer then has two effluent treatment systems to consider. Liquid drawn off from such a system is likely to be of high strength (more akin to silage leachate) but because the volume is relatively small it can be added to pond effluent.

When solid manures are applied to land the application loading rate is normally low enough (< 20 t/ha) to ensure that nutrient loading and runoff risk are minimal. Farmers who opt for the slurry approach to land application can focus on one delivery system. Slurries should be considered as very potent liquids. As nutrient concentrations can be relatively high, care must taken to ensure that optimal loading rates are not exceeded. Environmental risks also increase when slurries are applied to sloping land. Being semi-liquid there is greater risk of runoff should rain follow soon after land application. The extent of this risk is unknown, but needs to be quantified, as slurries are seen by increasing numbers of farmers as a viable land treatment option.

5.8 Analytical reporting from laboratories

Laboratory results used in this report have come from the three main analytical laboratories used for agricultural purposes in New Zealand. Each laboratory has *their* own unique method for reporting results. A brief summary of each laboratories' reporting style is presented in Table 11. All laboratories supply additional information if required, such as, nutrient loading at specific depths, or maximum application rate to stay within a particular N or K nutrient loading.

Table 11: Laboratory method of reporting manure results.

Laboratory/manure	Units	Comments
Hill Laboratories		
Liquid effluent	kg/m^3 [1]	Easier for farmers to work with kg's and m^3 than mg/L
Slurries	kg/m^3	
Solid effluents	kg/t [2]	Reporting in m^3 for solids is not practicable due to difficulties in determining density/SG which would match what is happening in the real world.
NZLabs		
Liquid effluent	%	Treated as fertilisers, so results presented like
Slurries	%	fertiliser products, eg., % (g/100g). Farmer can then
Solid effluents	%	compare NPK rating on Fertiliser bag, etc.) Samples homogenised and analysed on "as received" basis. [3]
ARL		
Liquid effluent	mg/L	Would consider changing units to kg's and m^3
Slurries	mg/kg	Results reported on both fresh and dry weight basis.
Solid effluent	mg/kg	Determining density/SG is not something that translates readily from field to laboratory.

[1] Conversion from g/m^3

[2] Conversion from mg/kg

[3] Weight/volume measurement for liquids and bulk density for slurries are included to allow volume conversions if required.

6. Recommendations for industry best practice and policy development

In New Zealand research efforts related to land application of animal effluents has focused upon liquid FDE (generally < 2% DM) application, the dominant form of effluent derived from dairy farming systems. This research has allowed the development of a soil and landscape risk framework that recommends some minimum management practices to achieve in order to keep FDE in the plant root zone (Houlbrooke and Monaghan 2010, DairyNZ 2011). The use of this framework presented in Table 12 does not seem directly applicable to dairy slurries and manures because their higher dry matter content and concentrated nutrient content means that the volumes applied are considerably lower and therefore a greater proportion of the effluent will remain on the soil surface post application as opposed to residing in the root zone or passing straight through it. However, aspects of table 12 do relate to slurry products such as the timing of slurry in relation to soil moisture as slurry still behaves as a liquid.

Table 12. Minimum criteria for a land-applied FDE management system to achieve.

Category	A	B	C	D	E
Soil and landscape feature	Artificial drainage or coarse soil structure	Impeded drainage or low infiltration rate	Sloping land (>7°) or land with hump & hollow drainage	Well drained flat land (<7°)	Other well drained but very stony^{X} flat land (<7°)
Application depth (mm)	< SWD*	< SWD	< SWD	< 50% of PAW#	≤ 10 mm & < 50% of PAW#
Instantaneous application rate (mm/hr)	N/A**	N/A**	< soil infiltration rate	N/A	N/A
Average application rate (mm/hr)	< soil infiltration rate	< soil infiltration rate	< soil infiltration rate	< soil infiltration rate	< soil infiltration rate
Storage requirement	Apply only when SWD exists	Apply only when SWD exists	Apply only when SWD exists	24 hours drainage post saturation	24 hours drainage post saturation
Maximum N load	150 kg N/ha/yr	150 kg N/ha/yr	150 kg N/ha/yr	150 kg N/ha/yr	150 kg N/ha/yr
Risk	High	High	High	Low	Low

* SWD = soil water deficit, [#] PAW = Plant available water in the top 300 mm of soil,

[X] Very stony= soils with > 35% stone content in the top 200 mm of soil

** N/A = Not an essential criteria, however level of risk and management is lowered if using low application rates

Given the difference in management required between FDE and slurry/manures we have developed a preliminary soil and landscape risk framework for successful land application of slurries and manures (Table 49). However this framework has been prepared using scientific principles for nutrient management and best practices recommended for the UK dairy industry based largely upon European research. The framework would therefore require ongoing validation and refinement over time as New Zealand research can be undertaken specific to our pastoral based dairy farming system. It should also be noted that most of the management practices recommended apply across all soil and landscape features. The only exception relates to some aspects of slurry management where its more liquid behaviour needs to take into account some of the risks posed by different soil and landscapes. Category E of the FDE framework is no longer required as it relates to water holding capacity which is generally not an issue for concentrated effluents that are applied in limited volume. Category E is therefore merged with Category D for the slurry and manure framework. In general management practices for FDE will relate to slurry management while best management practices for solid fertiliser will apply to solid manures.

In summary, Table 13 recommends that slurries should be applied to land at loading rates of < 50 m^3/ha and manures at loading rates < 3 t DM/ha. When being applied to a grazed pastoral landscape then we recommend a maximum N loading of 150 kg N/ha. However when applied to cut and carry or cropping systems, crop and site dependant factors need to take account of crop N requirement and deep soil mineral N status. We recommend that manures or slurries should not be applied to soils wetter than field capacity and that slurries should not be applied to high risk soils (Category A, B and C) unless there is a suitable soil water deficit to accommodate the application. Furthermore, we recommend that slurries and manures should not be applied if rain is forecast that would likely cause a runoff event within the subsequent 48 hour minimum (and recommended 10 day) period following application or if soil temperature is below 4 degrees C which suggests poor plant growth activity.

Table 13. Recommended best practice for land application of slurries and manures

Category	**A**	**B**	**C**	**D**
Soil and landscape feature	Artificial drainage or coarse soil structure	Impeded drainage or low infiltration rate	Sloping land (>7°) or land with hump & hollow drainage	Well drained flat land (<7°)
Application volume - slurry	< 50m^3/ha	< 50m^3/ha	< 50m^3/ha	< 50m^3/ha
Application volume - solids	<3 t DM/ha	<3 t DM/ha	<3 t DM/ha	<3 t DM/ha
Soil moisture at application - slurry	Application depth <SWD	Application depth <SWD	Application depth <SWD	Avoid saturation: field capacity or drier
Soil moisture at application - solids	Avoid saturation: field capacity or drier	Avoid saturation: field capacity or drier	Avoid saturation: field capacity or drier	Avoid saturation: field capacity or drier
Maximum N load - pasture	150 kg N/ha/yr	150 kg N/ha/yr	150 kg N/ha/yr	150 kg N/ha/yr
Maximum N load - crop	Crop and site dependant	Crop and site dependant	Crop and site dependant	Crop and site dependant
Tactical timing if not incorporated	> 10 days until runoff event (min 48 hrs)	> 10 days until runoff event (min 48 hrs)	> 10 days until runoff event (min 48 hrs)	> 10 days until runoff event (min 48 hrs)
Optimum time of year	Late spring	Late spring	Late spring	Late spring
Minimum soil temperature	4 ºC	4 ºC	4 ºC	4 ºC

As stored slurry will actively convey contaminants in drainage water we recommend that slurry is only stored on appropriate impervious surfaces such as those used to store FDE or on impervious surfaces that drain gravity separated liquids back into FDE storage. However solid manures would pose less risk from temporary storage on uncontained soil surfaces they will not freely drain contaminants under the influence of gravity. In the UK the Department of Environment, Food and Rural Affairs (Defra 2008b) recommends that temporary storage of solid manures in field heaps is allowable so long as the following conditions are met:

- The manure is solid enough to be stacked and does not give rise to free drainage
- Field heaps are not located within 10 m of a surface water body of drain or within 50 m of a borehole
- Field heaps are not located on land likely to be flooded or waterlogged
- Field heaps are not left in one location for more than 12 months.

We suggest that similar management practice should be recommended in New Zealand distinguishing between slurry and solid manure effluents.

7. Research gaps

As this programme has developed, it became apparent that there is a need to plug a number of key research gaps while considering all of the R&D components in a wider farm systems context to ensure we are developing management practices capable of achieving environmental aims (water quality, nutrient use efficiency, and greenhouse gas emissions) whilst maximising agronomic and economic benefits. There is plenty of international data in this area that can be drawn upon in order to help identify best management practices. However New Zealand has a pastoral based dairy farm system and its own climatic and soil conditions that are not necessarily represented within the international literature. An existing SFF project based in Otago and the Waikato will provide some basic data on the greenhouse gas footprint associated with housed animal wintering systems: while this will be used for developing preliminary BMPs for reducing emissions from wintering system, a broader and deeper research programme is required. Some key research gaps for manure and slurry management include but are not limited to:

- Gaseous emissions from storage facilities and potential mitigation options
- Understanding nutrient transformations during handling, solid separation and storage
- Determining separation efficiency of a range of solid separation techniques
- Development of farmer friendly nutrient value testing tools and protocols
- Risk of N, P and faecal microbial losses to water (surface runoff and leaching) following land application of slurries and manures.
    - Comparison of slurry (low DM) vs. manure (higher DM) effluent products
    - Comparison of surface deposits vs. rapid incorporation
    - Comparison of surface application vs injected or band spread (trailing shoe) application technology
    - Timing of application in relation to rainfall events
    - Influence of high vs. low risk soil on runoff loss and risk period
- Gaseous emissions following land application of slurries and manures and potential mitigation options and a comparison of different application technology such as trailing shoes in order to mitigate losses.
- Improving utilisation, quality, quantity and palatability of slurry and manure treated pastures
- Improved understanding of N mineralisation rates and fate from applied manures and slurries in New Zealand conditions in order to provide decision support tools for farmers
- The impact of slurry and manure land application on soil quality

- Ongoing development and refinement of best management practices to enhance system optimisation and provide enhanced environmental and agronomic outcomes
- Increased understanding of odour emissions during storage and application of stored manures and slurries and potential mitigation options.

The largest gaps in New Zealand relevant science relate to assessments of different land application techniques and effluent products on subsequent nutrient losses (water and gaseous) and subsequent nutrient use efficiency determination.

8. Conclusions

- Data gathered from 22 case studies shows that slurries and manure properties vary considerably depending upon the farm and effluent management system.
- Using default or typical values for different effluent systems provides a starting point for understanding the characteristics of different slurries and manures. Using this data in combination with either a representative analytical test or an Overseer nutrient budget assessment is strongly recommended.
- Data collected from the 17 case studies where land application loading rates were assessed suggests that current practice is within agronomic and environmental management recommendations (< 150 kg N/ha/yr for grassland and up to 250 kg N/ha/yr for cropped land dependent upon crop yield requirement and residual soil N supply).
- Data collected from the 16 case studies where land application distribution uniformity was assessed suggests that all application methods were poorly distributed compared to standard expected for liquid FDE. Slurry spreading systems were more accurate than muck spreaders.
- Best practice for land application loading rates would be to apply slurry at < 50 m^3/ha and manure solids < 3 t/DM/ha in late spring, once soil water deficits had begun to develop but before high volatilisation would result from sunshine and high temperatures. From our case study measurements we determined that 8 out of the 17 systems (47%) with measured land application had application quantities greater than international recommended limits for a single event.
- Land application during or shortly before significant rainfall (causing drainage or surface runoff) should be avoided. Best practice management in the UK suggests a minimum of 4 days between land application and subsequent surface runoff events in order to mitigate the risk of enhanced nutrient loss from the applied effluent.

- New Zealand relevant research is further required with regards to slurry and manure management to provide information with regards to land application techniques and effluent products on nutrient losses (water and gaseous) and nutrient use efficiency by the soil plant system.

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11. Appendix 1: Case study results

11.1 Case study 1

Location: Walton, Waikato
Effluent type: Bunker manure
Farm size: 215 ha
Herd size: 650 cows
Imported feed: 0.25 t DM/cow/yr (PKE)
Soil order: Granular
Sampling date: September, 2009

Two 60m covered HerdHomes® animal shelters are used for feeding a range of feed supplements for 14 hours/day for dry cows during winter and 14 hours/day during milking through to end of calving (shelter at night). Manure from the cows, captured in the shelters bunker, is utilised for its fertiliser value on the areas set aside for pasture renewal. The designated paddocks are used for growing maize crops.

To attain a suitable slurry consistency for spreading, an additional 12% of liquid was added from pond effluent, to the estimated 500m^3 of bunker manure. The effluent was injected at one end of the bunker storage while one slat was removed towards the opposite end and a vertical stirrer (Photo 1) was used to homogenise the manure into slurry.

The bunker manure from the animal shelter was pumped via vacuum pump into a 7.5m^3 slurry tanker (Photo 2). The slurry tanker had a rear delivery splash plate system. The farmer estimated that slurry would be applied at a rate of 25m^3/ha.

Photo 1: Vertical stirrer, designed by Richard Stewart, produces homogenous slurry in nearest bunker.

Photo 2: 15 cm diameter hose attached to slurry tanker for delivering slurry.

Table 14 shows the distribution pattern of the slurry, 3 collection trays were placed 4m left or right of centre and in middle of tractor path. The weight and volume of slurry collected was measured; the bulk density was 1.04 t/m^3.

Table 14: Spreading distribution pattern of slurry.

Slurry application	4m Left	Middle	4m Right	**Mean**
Volume - mean (m^3/ha)	48.4	36.0	36.2	**40.2**
Standard Deviation (m^3/ha)	24.3	14.9	22.8	**20.6**
Rate – mean (t/ha)	50.7	37.7	37.9	**42.1**

The application loading volume was measured at 40m^3/ha ($\pm$ 8m^3/ha), this equated to an approximate application depth of 4mm (Photo 3). The distribution pattern from the slurry tanker was uneven and varied with an application depth ranging from 1.5 mm to 5.1 mm depth.

Photo 3: Slurry being applied at 40m^3/ha to a paddock designated for a maize crop.

Chemical analysis of the slurry is presented in Table 15 and shows that the slurry was K-rich, suggesting that gaseous N losses may have occurred.

Table 15: Chemical composition (kg/m^3) of bunker slurry.

Sample	DM %	Total N	Min N	Total P	K	Total S	Org. C %	C/N ratio	% Min-N
1	7.0	3.32	1.3	0.6	5.2	0.3	2.3	6.8	39
2	9.9	3.99	1.2	0.9	5.4	0.4	3.3	8.4	29
3	9.5	3.58	1.2	0.9	4.7	0.3	3.2	8.7	31
Mean	**8.8**	**3.54**	**1.2**	**0.8**	**5.1**	**0.3**	**2.9**	**8.0**	**33**

The total nutrient loading to the maize crop at a mean application rate of 42 t/ha averaged:

- N = 149 kg/ha
- P = 31 kg/ha
- K = 214 kg/ha
- S = 13 kg/ha

At this site meticulous planning was undertaken to ensure the slurry spreading occurred smoothly. Two slurry tankers were in operation, each operator had a farm plan with paddock layout. Entry/exit points for paddocks were highlighted and routes planned so that tankers would not meet head-on on the same race.

11.2 Case study 2

Location:	Okaro, Bay of Plenty
Effluent type:	Bunker manure
Farm size:	140 ha
Herd size:	360 cows
Imported feed:	0.5 t DM/cow/year (PKE, kiwifruit)
Soil order:	Pumice/Recent
Sampling date:	October, 2009

Two 60m HerdHomes® Shelter sheds are used to winter the herd. Prior to this the farmer wintered cows on a wood chip pad. This farm has a challenging landscape and Rotomahana mud soils that are susceptible to pugging damage. The HerdHomes® sheds are also used for feeding during the late summer/early autumn period. Solids in the bunker (500m^3 capacity) are agitated using a home-made vertical stirrer that mixes manure into a slurry consistency. This slurry was spread via a 7.5m^3 slurry tanker (Photo 4) to all pastoral parts of the farm. Steep sidings are sprayed from top of ridges using the side-delivery system (Photo 5). The amount of slurry applied was highly variable due to wind changes, tractor speed and contour of land (Table 16). The bulk density of the slurry was 1.01 (± 0.01) t/m^3.

Table 16: Application rate (m^3/ha) from spreading pattern of side-delivery slurry tanker application.

Distance from tanker	3m	7m	9m
Contour - Flats	14.3	19.7	53.3
- Rolling	2.3	7.0	23.3
- Steep sidings	0.3	4.0	9.0



Photos 4 & 5: Side-delivery spreading system used for spraying flats and steep sidings.

Chemical analysis of samples (Table 17) shows the slurry being K-rich, a N:K ratio of 0.5 suggests large gaseous N losses from storage are occurring. The analysis also shows that 55% of the Total N is in plant available (mineral-N) form.

Table 17: Chemical composition (kg/m^3).

Sample	DM %	Total N	Min N	Total P	K	Total S	Org. C %	C/N ratio	% Min-N
1	4.1	2.24	1.33	0.30	5.15	0.20	1.2	5.4	59
2	4.6	2.46	1.34	0.35	5.27	0.23	1.4	5.7	54
3	6.0	2.69	1.37	0.53	5.29	0.31	1.9	7.1	56
Mean	**4.9**	**2.46**	**1.35**	**0.39**	**5.24**	**0.25**	**1.5**	**6.0**	**55**

At an average solids application rate of 14.6m^3/ha the following nutrients are applied:

- N = 36 kg/ha
- P = 6 kg/ha
- K = 78 kg/ha
- S = 4 kg/ha

Since this sampling occurred, the farmer has introduced a liquid draw-off system for the manure bunker in an effort to produce drier manures. The Bay of Plenty Regional Council has been monitoring this site and extra chemical analyses of HerdHomes® Shelter manures are available (Table 18).

Table 18: Chemical composition of HerdHomes® Shelter manure when either liquid (kg/m^3), slurry (kg/m^3) or manure (kg/t).

Effluent	% DM	N	P	K	S
Liquid (n=3)	2.5	2.4	0.04	6.2	-
Slurry (n=3)	11.4	2.6	0.80	5.4	0.2
Manure (n=2)	17.0	3.4	1.40	5.7	2.1

11.3 Case study 3

Location:	Waeranga, North Waikato
Effluent type:	Bunker manure
Farm size:	120 ha
Herd size:	400 cows
Imported feed:	2.15 t DM/cow/yr (maize silage, PKE, potatoes)
Soil order:	Gley
Sampling date:	November/December 2009

Two 60m covered HerdHomes® animal shelters are used for feeding a range of feed supplements to the Ayrshire herd. The herd is wintered to help relieve the stocking pressure on the heavy Gley soils during wet periods. Manure from the cows, captured in the bunker, is used to fertilise areas set aside for pasture renewal. The designated paddocks are used for growing crops either for maize silage or forage sorghum. The bunker manure was applied to cultivated ground as slurry via a 7.5 m^3 slurry tanker using a rear delivery splash plate system. As with Case Study 1 additional liquid (~12%) was added as FDE to the estimated 500m^3 of bunker manure using the same method. Bulk density of slurry was 1.07 $\pm$ 0.1 t/m^3.

The farmer estimated that slurry would be applied at a rate of 20m^3/ha. The application loading rate was calculated from the three field collection trays, placed at 4m intervals left and right of middle of spread. The average application was 53.3 and 27.1m^3 ha^{-1} ($\pm$ 6.0) for tractor speeds of 2.5 and 5 km/hr, respectively; this equated to an approximate application depth of 2.7mm (Table 19). The distribution pattern from the slurry tanker was uneven, partly due to very uneven ground surface (Photo 6) and partly due to the splash plate not being perfectly square to flow. The result was a variable application range of 1.5mm to 11.2mm depth.

Table 19: Application rate (t/ha) from slurry tanker to cropping area.

Tractor Speed	4m Left	Centre	4m Right
2.5 km/hr	30.4	41.4	43.8
	35.7	59.8	44.9
	56.7	111.5	82.3
	80.9	76.5	57.1
	42.9	32.1	53.1
	49.3	23.3	38.5
Average	**49.3**	**57.4**	**53.3**
5.0 km/hr	19.3	34.0	22.2
	26.2	39.7	22.3
	36.3	23.3	49.4
	16.5	25.7	29.0
	15.1	26.3	32.1
	18.9	29.4	22.9
Average	**22.0**	**29.7**	**29.7**

Photo 6: Spreading pattern from rear-delivery Pearson slurry tanker.

Slurry samples were collected during the emptying of the HerdHomes® Shelter on two occasions (November and December). The chemical composition of the slurries is presented in Table 20. Chemical analysis indicates a high concentration of K relative to other major nutrients and that 37% of Total N is in mineral-N form. The low variation in chemical composition between samples, gauged by standard deviation, indicates that the vertical stirrer was effective in producing homogeneous slurry.

Table 20: Chemical composition (kg/m^3) of homogenised HerdHomes® Shelter bunker slurry.

Sample	DM %	Total N	Min N	Total P	K	Total S	Org. C %	C/N ratio	% Min-N
1	15.4	5.89	2.03	1.52	8.99	0.89	5.6	9.4	35
2	15.1	5.86	2.05	1.49	8.46	0.88	5.5	9.5	35
3	14.3	5.72	2.13	1.38	8.24	0.94	5.5	9.7	37
4	14.7	5.09	1.92	1.29	6.64	0.92	5.3	10.5	38
5	15.1	5.17	1.98	1.26	6.60	0.86	5.3	10.3	38
6	15.7	5.46	2.15	1.40	6.87	0.94	5.6	10.2	39
Mean	**15.1**	**5.53**	**2.04**	**1.39**	**7.63**	**0.90**	**5.5**	**9.9**	**37**
SD (±)	0.5	0.35	0.10	0.10	1.05	0.03	1.1	0.5	2

The total load of nutrients applied at average of 40 t/ha to the maize crop averaged:

- N = 221 kg/ha
- P = 56 kg/ha
- K = 305 kg/ha
- S = 36 kg/ha

E. coli was measured on three slurries at the second sampling in December, 2009. The mean *E. coli* enumerated was 4x10^6 MPN/100 g.

11.4 Case study 4

Location:	Waharoa, Waikato
Effluent type:	Bunker manure
Farm size:	83 ha
Herd size:	360 cows (split calving)
Imported feed:	3.5 t DM/cow/year
Soil order:	Allophanic/Gley
Sampling date:	November, 2009

Two 60m HerdHomes sheds are used for feeding/sheltering cows for at least 5 hours per day throughout the year. During winter/early spring, the shelters are used for approximately 20 hours/day. This farm has a very high milk production (3,065 kg DM/ha) and the cows diet is heavily supplemented (i.e., pasture only 35% of diet) with a wide range of imported feeds (maize silage, PKE, broll, molasses, potatoes, kiwifruit),

Manure solids captured in the concrete bunker (500m^3 capacity) are removed during spring and applied to pastoral paddocks. The solids are spread via a 12t orbital muck spreader as required. This muck spreader can handle both solids and slurries. Stored solids are applied to paddocks with lower fertility. Six collection trays were used for the spread distribution measurements. The average application depth was 7.6t/ha (Table 21), this was lower than the farmers' estimate of 10t/ha. The amount applied was highly variable due to wind changes and tractor speed.

Photo 7: Manure being removed from the HerdHomes® Shelter bunker.

Photo 8: HerdHomes® Shelter bunker manure applied to crop paddock.

Table 21: Spreading pattern (rate applied (t/ha) v distance from spreader (m)).

Distance	3m	5m	7m	9m	11m	13m
Mean (t/ha)	10.5	8.4	6.6	9.4	10.7	7.4
Std. Dev. (±)	8.0	4.9	6.7	13.5	15.1	8.5

Chemical analysis of HerdHomes® Shelter manure samples revealed a %DM value of 17%, a K-rich material (N:K ratio of 0.8) indicating lower N gaseous losses than slurry samples (Table 22).

Table 22: Chemical composition (kg/t).

Sample	DM %	Total N	Min N	Total P	K	Total S	Org. C %	C/N ratio	% Min-N
1	16.9	6.10	2.44	1.37	7.05	0.57	6.6	10.8	40
2	16.4	6.40	2.47	1.40	7.17	0.54	6.3	9.9	39
3	16.8	5.58	2.57	1.42	8.09	0.63	6.6	11.8	46
Mean	**16.7**	**6.02**	**2.50**	**1.40**	**7.44**	**0.58**	**6.5**	**10.8**	**42**

The amount of nutrients in HerdHomes® Shelter solids applied at an average 7.6 t/ha:

- N = 46 kg/ha
- P = 11 kg/ha
- K = 57 kg/ha
- S = 4 kg/ha

11.5 Case study 5

Location:	Orini, Waikato
Effluent type:	Bunker manure
Farm size:	80 ha
Herd size:	240 cows
Imported feed:	870 kg DM/cow/year (PKE, Tapioca, Canola, Molasses, Straw)
Soil order:	Gley
Sampling date:	December, 2009

Two 39m HerdHomes® shelters are used that cows spend two days in, one day out of. From mid-June all dry cows are kept inside while the milkers are brought inside only when soil conditions are wet. For the rest of the year the HerdHomes® Shelters are used for about 4hrs/day. The farm is prone to being very wet over winter/early spring.

Since the sampling, both HerdHomes® Shelters have been extended to 54 m long so that the whole herd can now be accommodated.Prior to manure being emptied, liquid was sucked out (Photo 9) and spread separately via slurry tanker. Manure solids are spread via an 18t muck spreader (Photo 10). Estimated application rate was 5t/ha however the measured rate averaged 11t/ha. The upper quartile distribution of uniformity (UQD) = 2.13.

Photo 9: Liquid sucked out of manure bunker before solids removed.

Photo 10: Muck spreader being loaded with solids.

Chemical analysis of HerdHomes® Shelter manure (Table 23) shows that solids content was 20% DM, K-rich manure (N;K ratio 0.7), mineral N 31% of Total N.

Table 23: Chemical composition (kg/t) of bunker manure.

Sample	DM %	Total N	Min N	Total P	K	Total S	Org. C %	C/N ratio	% Min-N
1	19.9	6.33	1.98	1.51	8.59	0.85	8.0	12.6	31
2	23.6	7.10	1.93	2.08	10.19	1.24	9.2	13.0	27
3	16.7	6.07	2.21	1.40	8.78	0.83	6.5	10.7	36
Mean	**20.1**	**6.50**	**2.04**	**1.66**	**9.19**	**0.97**	**7.9**	**12.1**	**31**

The application rate of HerdHomes® Shelter solids from the muck spreader applied to pasture were measured in five collection trays (Table 24). The first run was the first one of the day and the lighter rate applied may have been due to the operator's initial "settling in" routine.

Table 24: Application rate (t/ha) and spreading pattern from the muck spreader.

Run	6m LH	3m LH	0 (Centre)	3m RH	6m RH	**Average**
1	1.80	3.91	3.67	7.80	3.23	**4.09**
2	10.80	13.34	35.40	8.37	7.51	**15.09**
3	3.51	14.34	35.40	8.09	22.51	**16.77**

At an average application rate of 12t/ha the following nutrients are applied:

- N = 78 kg/ha
- P = 20 kg/ha
- K = 110 kg/ha
- S = 12 kg/ha

E. coli was measured on the three solid manures in December, 2009. The mean *E. coli* enumerated were 1x10^7 MPN/100g.

11.6 Case study 6

Location:	Lichfield, South Waikato
Effluent type:	Rain gun used to empty storage pond
Farm size:	100 ha
Herd size:	300 cows
Imported feed:	0.25 t DM/cow/yr (PKE)
Soil order:	Allophanic
Sampling date:	April, 2010

The farm consisted of rolling and easy hill country. FDE is stored in a holding pond and an agricultural contractor is employed to empty it before winter. A rain gun (cannon) was used in conjunction with a 260HP pump which delivers an application rate up to 150m^3/hr. The rain gun has an adjustable head which can be used for spraying onto steep hill sidings. The system was run off the tractors' PTO. Another contractor was at the effluent pond, agitating the pond contents to get some mixing of liquids and solids, and regulating the rate that effluent was pumped to the spraying contractor. Various factors that could have influenced the measured application depth are detailed in Table 25. This operation required the two contractors to keep in close radio contact with each other.

Table 25: Factors that could have influenced the variable effluent application depth from the rain gun.

Land contour	1 Flat	2 Rolling	3 Flat
Hose length (m)	500	500	300
Pumping pressure (psi)	130	130	100
Wind strength	nil	breeze	nil
Application depth (mm)	8.2	7.0	6.2

A series of collection trays (22) were laid out at 2m intervals from the spray head. The rain gun was adjusted to spray in a 120^o arc (Photo 11). After every 4 to 5 passes, the tractor was moved to a new area for spraying. The spreading distribution pattern of the rain gun from three runs with differing land contours is presented in Figure 11. The rain gun has the ability to spread FDE over a large distance - on the second run some FDE went another 2-3m past the 44m tray. The area covered (the weighted number taking into effect the rain gun's spraying arc) was ~1,500m^2 while the average application depth was 7.1mm. The upper quartile distribution (UQD) uniformity was 1.68.

The chemical composition of the pond effluent (Table 26) shows a solids content (1.7%) typical of fresh FDE. Pond stirring was effective in producing a uniform effluent as indicated by chemical analysis. This pond effluent was N-rich (N:K ratio 1.6) and 24% of Total-N was plant available.

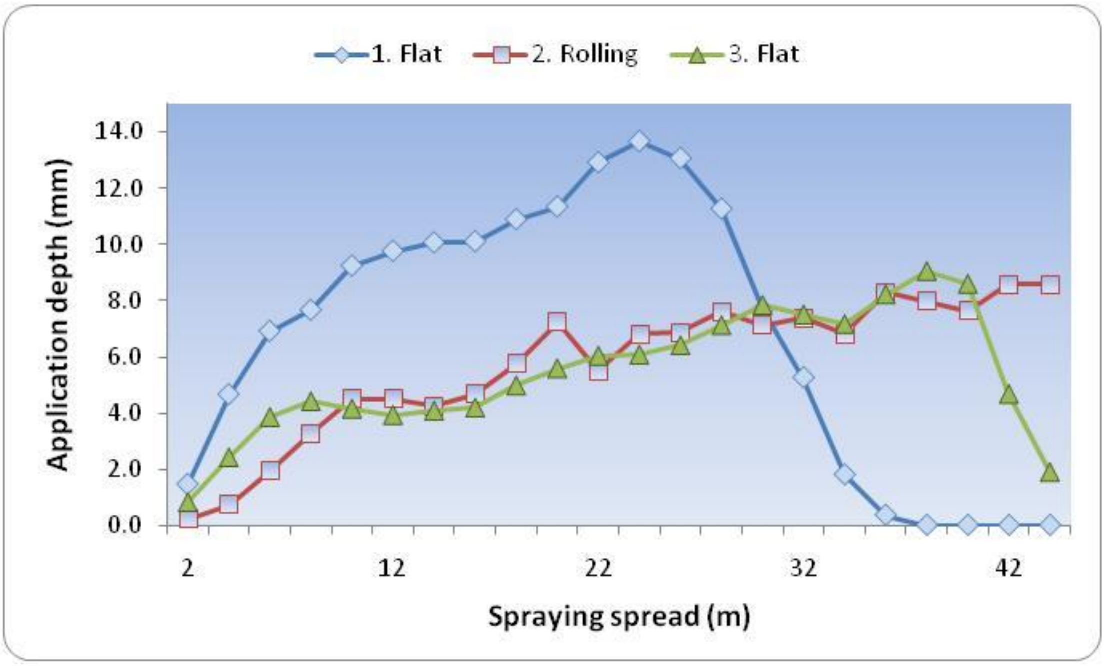

Figure 11: Spreading pattern from SIME rain gun on different land contours.

Table 26: Chemical composition (kg/m^3) of the pond effluent.

Sample	DM %	Total N	Min N	Total P	K	Total S	Org. C %	C/N ratio	% Min-N
1	1.7	0.64	0.15	0.13	0.35	0.09	0.6	9.4	24
2	1.7	0.60	0.15	0.14	0.38	0.09	0.6	10.1	25
3	1.7	0.63	0.15	0.11	0.41	0.09	0.6	9.6	23
Mean	**1.7**	**0.62**	**0.15**	**0.13**	**0.38**	**0.09**	**0.6**	**9.7**	**24**

Total nutrients applied at 7.1mm depth averaged:

- N = 44 kg/ha
- P = 9 kg/ha
- K = 27 kg/ha
- S = 6 kg/ha

Photo 11: Pond effluent being spread by rain gun.

11.7 Case study 7

Location:	Dannevirke, Wairarapa
Effluent type:	Mechanical solid separation
Farm size:	222 ha
Herd size:	650 cows
Imported feed:	1 t DM/cow/year
Soil order:	Pallic
Sampling date:	February 2010

Effluent from the rotary shed, feed pad and feed bunkers (Photo 12) initially goes to a 144m^3 dairy sump. The effluent stream then passes through a screw-press that separates out the solids (Photo 13). The post-separated effluent is then stored in a large synthetically lined holding pond (7.5 million litres).

The screw-press separated solids out at ~ 1kg/min from an effluent input of 300 L/min. The separated solids are then stored in uncovered concrete lined bunkers (2 x 20m^3 each). An extra bunker is also available for storing either feed supplements or manure solids if needed. The solids are spread on pastures/crops as required using a side-delivery muck spreader (Photo 14). Spreading pattern details are presented in Table 27 and show that application rate increased with increased tractor speed. Normally the reverse would be true.

Photo 12: Feed pad, solids separator, solids storage and holding pond.

Photo 13: Screw-press solids separator.

Table 27: Spreading distribution (t/ha) from the side-delivery muck spreader.

Run	Speed (kph)	2m	4m	6m	8m	10m
1	8	13.4	3.4	0.2	0	0
2	12	36.3	2.6	0.3	0	0
3	15	77.4	5.4	0.3	0	0
Mean		**42.4**	**3.8**	**0.3**	0	0

Photo 14: Side-delivery muck spreader in action.

The post-separated FDE is applied to pasture via a low application irrigation system. Six sprinklers are used and normally operate for 4-10 hours/day. Twin stand-off pads with a total area of 960 m^2 are used for calving 650 cows adjacent to a second feed pad on the farm. Cows spend an average of 21 hrs per day on the pads. The pads have a 30 cm woodchip cover over river gravel with a compacted clay base. The stand-off area receives occasional use outside the wintering period. Solids from the pad were cleaned out in late October and stored in an open concrete lined bunker and held there until utilised for a summer brassica crop. Chemical composition of different samples collected is presented in Table 28.

At average solids application rate of 15.5 t/ha the following nutrients are applied:

- N = 54 kg/ha
- P = 13 kg/ha
- K = 16 kg/ha

Table 28: Chemical composition of effluents (liquids as kg/m^3, solids as kg/t).

Source	DM %	Total N	Mineral N	Total P	K	Org. C %	C/N ratio	% Min-N
Raw effluent								
-	0.5	0.25	0.16	0.08	0.37	0.2	8.2	64
Effluent after solids separation								
-	0.2	0.10	0.07	0.05	0.21	-	-	70
Separated solids								
Fresh	22.2	2.58	0.01	0.41	0.63	9.4	36	1
> 1 wk	27.0	2.77	0.01	0.47	0.58	11.8	43	1
> 2 mth	19.7	2.75	0.03	0.57	0.90	7.8	28	1
Applied	19.3	2.66	0.01	0.54	1.03	7.8	29	1
Average	**22.1**	**2.69**	**0.02**	**0.79**	**0.79**	**9.2**	**34**	**1**
Stand-off solids								
> 1 mth	28.9	3.35	0.01	0.74	0.92	11.8	35	0
> 6 mth	30.4	3.68	0.01	0.94	1.16	7.5	20	0
Average	**29.7**	**3.51**	**0.01**	**0.84**	**1.04**	**9.7**	**28**	**0**

11.8 Case study 8

Location:	Rongatea, Manawatu
Effluent type:	Mechanical solids separator
Farm size:	220 ha
Herd size:	520 cows
Imported feed:	0.5 t DM/cow/year
Soil order:	Gley
Sampling date:	February 2010

FDE from the dairy shed goes to a 30,000L tank that is stirred twice daily. A screw press type solid separator is used to remove solids (Photo 15). The separated solids are stored in a covered concrete bunker with 50m^3 capacity (Photo 16). The solids are spread via a muck spreader when needed. This spreader is like a silage feed-out wagon with rear delivery system and has a 10t capacity. Stored solids are applied to cropping areas (mainly maize) prior to planting.

Photo 15: Solid separator.

Photo 16: Covered solids bunker.

The FDE liquid post separation is gravity fed to a 3000 m^3 storage pond. An enclosed impellor pump is used to deliver FDE to a travelling irrigator for land application. No spreading distribution data for solids was possible at this site. A covered stand-off pad (390m^2) is used to house 150 cows for 8 weeks. The bedding comprises a post-peelings base with straw added daily on the top (Photo 17). Accumulated solids in the barn were cleaned out in January and stockpiled in the open. After semi-composting, the solids would be applied to maize cropped areas. Table 29 presents a summary of chemical composition of the various manures.

Photo 17: Post peeling base being prepared in barn for next season.

Table 29: Chemical composition of effluents (liquids as kg/m^3, solids as kg/t).

Source	DM %	Total N	Mineral N	Total P	K	Org. C %	C/N ratio	% Min-N
Raw effluent								
-	0.6	0.19	0.09	0.09	0.39	0.2	10..8	47
Effluent after solids separation								
-	0.3	0.18	0.14	0.07	0.48	-	-	78
Separated solids								
Fresh	20.9	2.07	0.01	0.48	0.60	8.8	43	1
> 1 wk	22.8	2.18	0.01	0.42	0.68	9.5	44	1
> 1 mth	21.9	3.02	0.03	0.75	1.04	8.0	27	1
Average	**21.9**	**2.42**	**0.02**	**0.55**	**0.77**	**8.8**	**38**	**1**
Stand-off solids								
Top	45.5	3.82	1.35	1.54	10.67	6.1	16	35
North	33.0	5.30	1.35	1.52	14.17	8.5	16	26
South	34.5	4.60	1.55	1.40	12.28	8.2	18	34
Average	**37.7**	**4.57**	**1.42**	**1.49**	**12.37**	**7.6**	**17**	**32**

11.9 Case study 9

Location:	Opiki, Manawatu
Effluent type:	Feed pad scraped solids
Farm size:	180 ha
Herd size:	600 cows
Imported feed:	1 t DM/cow/yr (PKE, maize silage & straw)
Soil order:	Gley
Sampling date:	February 2011

The herd uses a feed pad twice daily. Supplements are fed out in bins. The feed pad has a slope to drain liquid effluent while solids are scraped to a 10m x 10m concrete bunker (Photo 18). The bunker is cleaned once/month throughout the year, except during spring when this is a weekly event.

Photo 18: Feed pad scraped solids being loaded into muck spreader.

The solids are spread onto pasture by an agricultural contractor using an orbital 12t muck spreader. The 200HP tractor tows the muck spreader which has a side-delivery system. The farmer estimated that solids would be applied at a rate of 22.5 m^3/ha. Scraping, loading and then transporting the solids to the paddock would ensure that some mixing occurs within the solids. However, field observations indicated that large clumps of solids are present that prevents even land application (Photo 19). The manure solids application loading rate was measured over two loads at 29.2 and 15.8 t/ha. The distribution pattern from the muck spreader was uneven and variable with an application depth ranging from 1 mm to 20 mm depth (Figure 12). The UQD was 2.01. Chemical composition of the feed pad solids is presented in Table 30.

Photo 19: Manure solids being spread via side delivery orbital muck spreader.

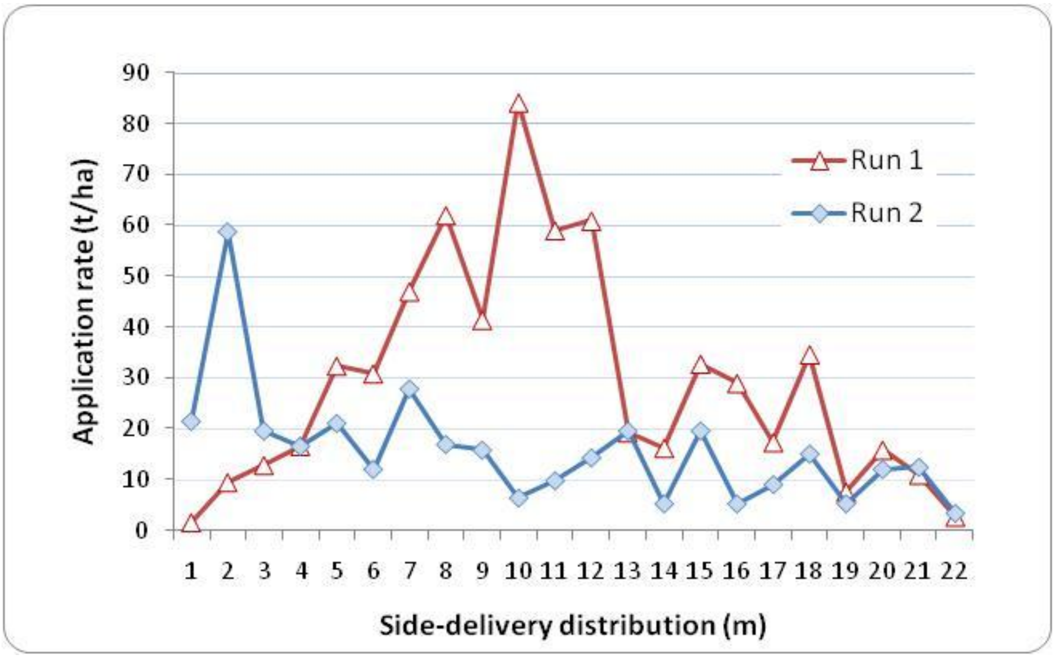

Figure 12: Solids spreading pattern from two runs of orbital spreader.

Table 30: Chemical composition (kg/t) of feed pad solids.

Sample	DM %	Total N	Min N	Total P	K	Total S	Org. C %	C/N ratio	% Min-N
1	21.5	5.7	0.7	1.2	7.1	0.7	7.5	13.3	13
2	18.1	5.1	0.5	1.1	7.2	0.8	6.4	12.5	10
3	18.8	5.2	0.2	1.1	7.9	0.7	6.3	12.2	4
Mean	**19.5**	**5.3**	**0.5**	**1.1**	**7.4**	**0.7**	**6.8**	**12.6**	**9**

At an average application rate of 6.5 t/ha the following nutrients are supplied:

- N = 120 kg/ha
- P = 26 kg/ha
- K = 166 kg/ha
- S = 16 kg/ha

11.10 Case study 10

Location:	Marton, Manawatu
Effluent type:	Weeping wall
Farm size:	550 ha
Herd size:	1,400 cows
Imported feed:	1.5 t DM/cow/yr (grass silage, PKE, maize silage)
Soil order:	Pallic
Sampling date:	February 2011

This dairy farm feeds their herd twice daily on a concrete feed pad. Effluent goes to a stone trap then to a sump with 2 days storage capacity, and then is pumped to two weeping walls (Photos 19 & 20). The two weeping walls measure: 40 m L x 8 m W x 2 m D (640m^3 each). The 8 m width design was used because that is within the reach of the digger bucket (Photo 21). The weeping wall consists of a wall of horizontal wooden slats to retain the solids that let the liquid drain through. An agricultural contractor is used to dig out the solids from the weeping wall every two months (Photo 22).

Photos 20 & 21: Weeping wall solids and post separated effluent in pond.

Separated liquid effluent then goes into a holding pond (10,000 m^3 capacity) that has been sealed with a cement/clay mix. Effluent from the pond is land applied via a centre-pivot irrigator. The solids are spread onto pasture using a muck spreader with a 7 m^3 capacity (Photo 23). A 100HP tractor tows the muck spreader which has a side-delivery system. The farmer estimated that slurry would be applied at a rate of 5 t/ha.

Photo 22: Loading solids.

Photo 23: Muck spreader.

The mean application loading rate was measured over two loads at 5.1 and 7.9 t/ha. The UQD uniformity = 2.03. The distribution pattern from the muck spreader was higher closer to the muck spreader and tapering off out to 11m (Figure 13).

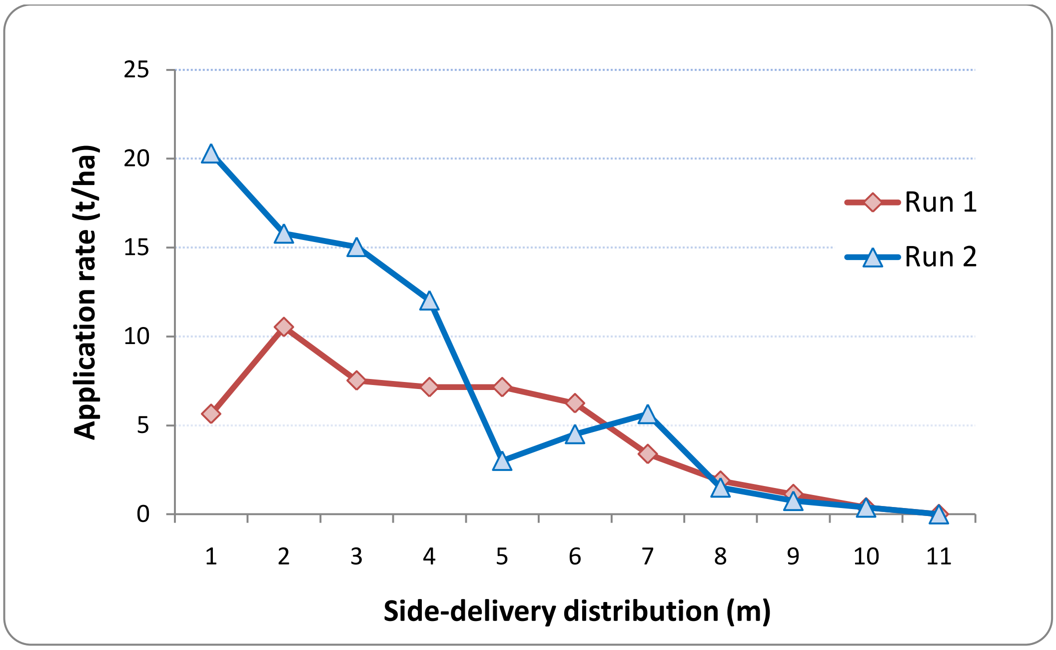

Figure 13: Solids spreading pattern from Abbey muck spreader from two runs.

Chemical composition of the effluents sampled is presented in Table 31.

Table 31: Chemical composition of effluent streams (liquids in kg/m^3, solids in kg/t).

DM %	Total N	Mineral N	Total P	K	Total S	Org. C %	C/N ratio	% Min-N
Raw effluent								
1.8	0.72	0.32	0.19	0.55	0.09	0.6	8.3	44
Effluent after Weeping Wall								
0.3	0.28	0.19	0.08	0.44	0.02	0.1	2.9	67
Weeping wall solids								
24.6	2.7	0.06	0.6	0.8	0.4	3.8	13.8	2
23.1	2.7	0.05	0.5	0.8	0.4	2.3	8.9	2
16.4	2.3	0.08	0.5	0.7	0.4	5.1	22.0	4
21.4	**2.6**	**0.07**	**0.5**	**0.8**	**0.4**	**3.7**	14.9	**3**

At an average application rate of 6.5 t/ha the following nutrients are supplied:

- N = 17 kg/ha
- P = 3 kg/ha
- K = 13 kg/ha
- S = 1 kg/ha

11.11 Case study 11

Location:	Marton, Manawatu
Effluent type:	Mechanical solid separation
Farm size:	220 ha
Herd size:	820 cows
Imported feed:	2 t DM/cow/year (maize silage & PKE)
Soil order:	Pallic
Sampling date:	February 2011

This dairy farm has a 60 m L x 70 m W covered feed pad. The feed pad is mainly used in the summer for feeding and shade (3-5 hrs/day). Effluent drains to a long rectangular sump that runs along the face of the feed pad. Effluent is then pumped through a screw-press solids separator (Photo 24). The solids drop into a concrete lined bunker (open) while the post-separated liquid effluent is held in a storage tank before being land applied to a 120 ha effluent block via a pivot irrigator. Solids are applied to the non effluent pastoral block.

Results of chemical composition from this site (Table 32) showed differences to other mechanically separated solids. The raw effluent had a very low % DM content and was N-rich, as was the post separated effluent. The solids content averaged 25% DM, N concentrations were higher those of K, which were more similar to those for P and S.

Photo 24: Screw-press solids separator on stand.

Table 32: Chemical composition of effluent streams (liquids in kg/m^3, solids in kg/t).

Sample	DM %	Total N	Min N	Total P	K	Total S	Org. C %	C/N ratio	% Min-N
Raw effluent									
	0.3	1.31	0.91	0.02	0.23	0.09	0.1	0.8	69
Effluent after solids separator									
	0.3	0.89	0.59	0.01	0.24	0.07	0.1	1.1	68
Separated solids									
1	24.3	3.44	0.02	0.54	0.72	0.54	9.9	28.8	1
2	30.6	4.24	0.02	0.70	0.79	0.70	12.8	30.2	1
3	24.1	3.21	0.04	0.50	0.54	0.54	9.2	28.6	1
4	23.1	4.20	1.03	0.20	0.38	0.46	10.0	23.8	24
5	21.8	3.77	0.95	0.24	0.38	0.47	9.3	24.6	25
Mean	**24.8**	**3.77**	**0.04**	**0.44**	**0.56**	**0.54**	**10.2**	**27.2**	**10**

It was not possible to collect any solids spreading distribution data at this site.

11.12 Case study 12

Location:	Mangakakia Valley, Northland
Effluent type:	HerdHomes® Dairyard bunker manure
Farm size:	360 ha
Herd size:	830 cows
Imported feed:	0.675 t DM/cow/yr (maize, PKE, hay)
Soil order:	Brown
Sampling date:	May, 2010

This farm has a two 60 m HerdHomes® animal shelters plus a HerdHomes® Dairyard. A Dairyard is a HerdHomes-like structure that joins with the milking shed and takes the place of a conventional holding yard (Photo 25). Several Dairyards are currently being evaluated by Fonterra as an alternative to current dairy shed design. Large savings in water usage are being reported by farmers.

Photo 25: HerdHomes® Dairyard attached to milking shed, HerdHomes® shelter is in background.

This Northland farm area is prone to being winter wet and summer dry. The HerdHomes® Shelter are used daily all year: 23.5hrs (winter), 6 hrs (spring), 8 hrs (summer), 10hrs (autumn). The Dairyard is used daily over the 305 day lactation. Dairyard manure is captured in bunkers similar to the HerdHomes® Shelter but set at right angles, so in a series of bays. This design allows for periodic emptying to occur by lifting 5-6 slats for tractor access and so causes minimal disruption during the lactation. As a result of cow flow the manure accumulation is different between the bays (Figure 14). The bay closest to the entry/exit of the Dairyard may also receive scraped manure accumulated on the outside concreted area. This means that these bays fill more quickly and therefore require more frequent emptying (Figure 15).

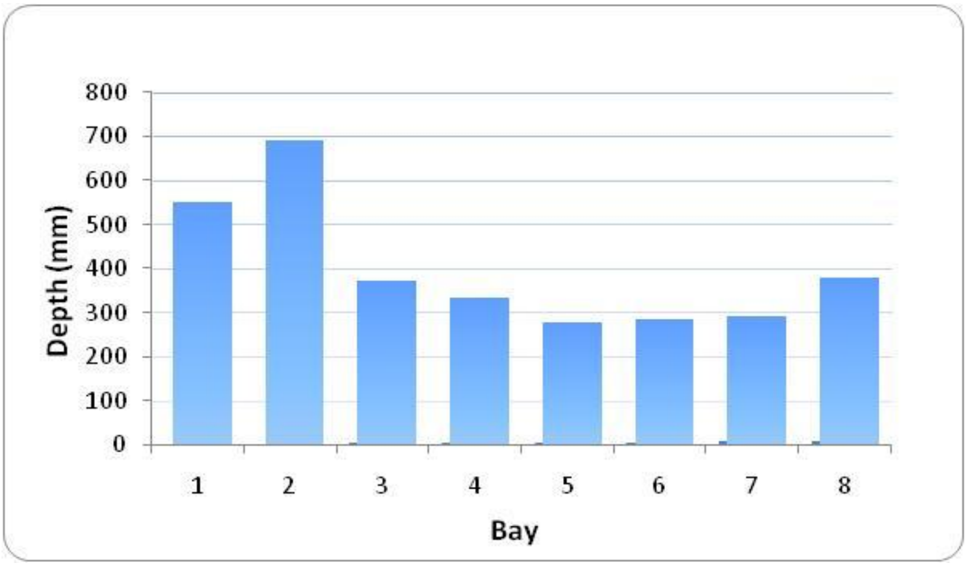

Figure 14: Manure depth in individual bays (where 1 is closest to entry/exit of Dairyard).

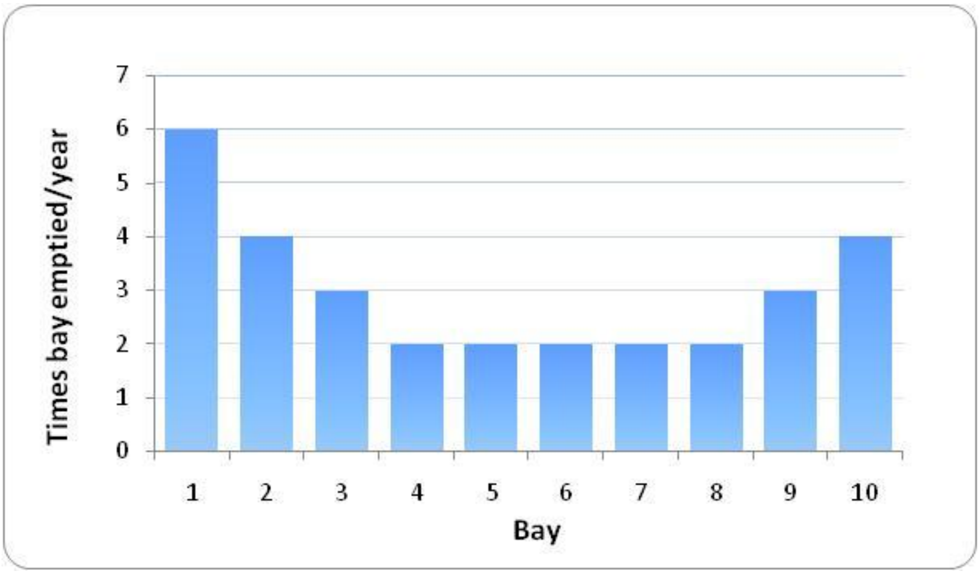

Figure 15: Number of times individual bays require emptying.

Since the Dairyard has been operational it has been discovered that having a weeping wall fitted 15 cm from the internal longitudinal wall has been effective at removing liquid, hence volume, from these bays meaning that less frequent emptying are required and a drier solids material is produced (Photo 26). The timber boards were bevelled to allow for a chainsaw width gap. The liquid effluent is drained off to a 10 m^3 tank for storage before land application.

Photo 26: Weeping wall inserted near back of manure bay to drain off liquid.

Solid manure is scooped out by tractor with a modified bucket (Photo 27) and loaded into a muck spreader with 9 m^3 capacity (Photo 28). Solids are land applied to pastoral areas of the farm, particularly to paddocks with low fertility.

Photo 27: Modified bucket to reduce manure spillage when emptying bunkers.

Photo 28: Dairyard solids spread via muck spreader.

A 140 HP tractor was used for spreading the manure solids for land application. The tractor PTO was run at 1,000 rpm. The distribution pattern of solid manure shows uneven spread at the centre where manure spilled out (Figure 16). The average application rate was 32 t/ha (± 21) but this was heavily influenced by higher application rates in the middle, if more typical values are used then the application rate would be 17 t/ha. This was still above the farmers' estimate of 10 t/ha. The UQD uniformity was 2.84. At 32 t/ha, 269 kg N/ha would be applied versus 143 kg N/ha at 17 t/ha. Chemical composition of the HerdHomes® Shelter Dairyard solids is presented in Table 33.

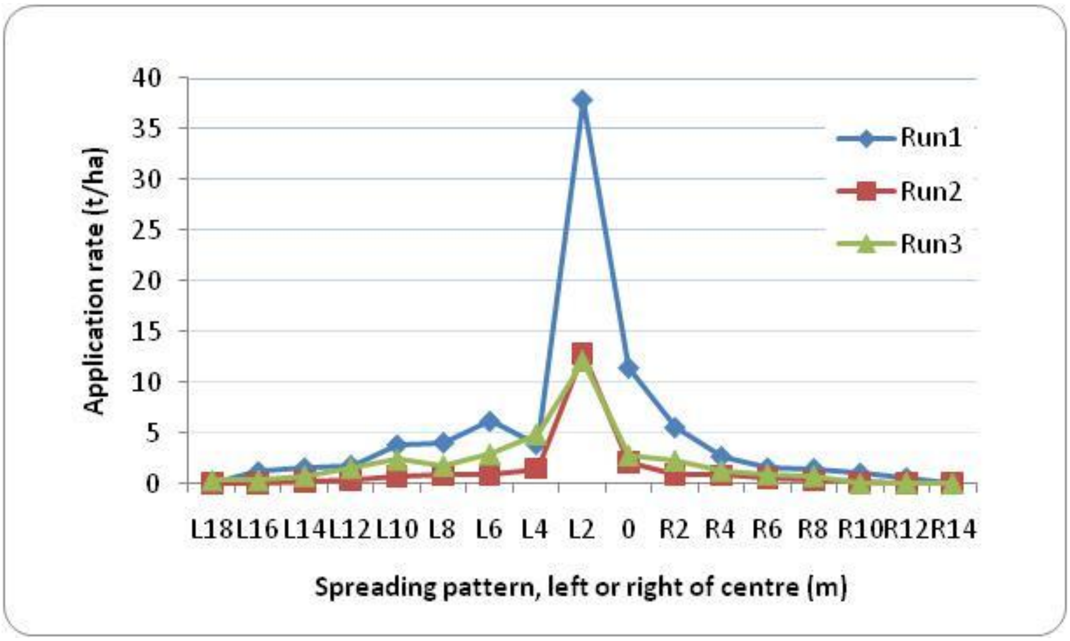

Figure 16: Manure distribution pattern from the muck spreader.

Table 33: Chemical composition (kg/t) of Dairyard bunker manure at Site 1.

Sample	DM %	Total N	Min N	Total P	K	Total S	Org. C %	C/N ratio	% Min-N
1	23.8	6.6	1.6	1.9	7.6	0.9	8.5	13	24
2	39.4	12.9	1.7	3.6	11.9	1.6	12.9	10	13
3	22.4	5.6	0.7	1.6	2.1	0.5	9.6	17	13
Mean	**28.5**	**8.4**	**1.3**	**2.4**	**7.2**	**1.0**	**10.3**	**13**	**16**

An additional sampling was undertaken at another HerdHomes® Dairyard site near Mangawhai in Northland (Table 34). This HerdHomes® Dairyard is the third to be built in Northland. Liquid is drained off to increase solids storage volume and achieve drier manure for muck spreading (Photo 29). The liquid is drained to the effluent holding pond.

Table 34: Chemical composition (kg t) of Dairyard bunker manure at Site 2.

Sample	DM %	Total N	Min N	Total P	K	Total S	Org. C %	C/N ratio	% Min-N
1	26.8	5.1	0.7	1.6	4.7	0.7	10.0	20	14
2	19.5	6.3	0.9	1.2	6.1	0.6	7.0	12	14
3	33.2	8.2	0.5	2.0	13.1	1.5	10.0	12	6
Mean	**26.5**	**6.5**	**0.7**	**1.6**	**8.0**	**1.0**	**9.0**	**14**	**11**

The manure analysis indicates that both farms produce a solid product with similar physical and chemical characteristics. The solids content averaged 27% DM; the concentrations of N, P and K reflect differing feed inputs and level of farm intensity.
The C/N ratios of 13-14 are typical of mature composts. The proportion of mineral-N (11-16%) indicates that slow release availability to plants would occur.

Photo 29: Site 2 farm with dry solids in HerdHomes® Dairyard bay.

11.13 Case study 13

Location:	Te Poi, Waikato
Effluent type:	Static screen solids
Farm size:	73 ha
Herd size:	350 cows
Imported feed:	2.2 t DM/cow (maize silage & grain, PKE, soya)
Soil order:	Allophanic
Sampling date:	March, 2011

The farmer suffered from blockages to his effluent irrigator from feeding supplements on the feed pad and wanted solids removed before pond storage so he would have a more dilute effluent for land application. A static screen was installed on a raised platform with the storage bunker below (Photo 30). Stirred effluent is pumped from the dairy sump to the top of the static screen where it comes over the top (much like a weir). The compact screen has a metal mesh of fine gauge to allow liquid to drain through but doesn't allow solids through. The screen is curved and the solids merely tumble forward and into the solids bunker below. Occasionally a 30 second hose down of the screen is required to clean the fine mesh. Maintenance requirements are low as there are no moving parts for the screen and power is only required for the pump. As the solids accumulate in the bunker the static screen is moved along the top of the bunker (Photo 31).

Photo 30: Static screen sited above storage bunker.

Photo 31: Screen can be moved along top of solids storage bunker. The storage bunker is in the process of becoming covered.

Chemical composition of the effluent that has passed through the static screens is presented in Table 35.

The solids content of 11% DM is approximately half that obtained from the mechanical screw-press separators. While the nutrient content in the solids is also lower than those from mechanical separators the nutrients in the liquid fraction appears to be higher. The static screens cost approximately half the amount of mechanical separators.

Table 35: Chemical composition (kg/m^3) of Static screen liquids and solids.

Sample	DM %	Total N	Total P	K	Total S	Ca	Mg	Na
Raw FDE	2.5	0.89	0.20	0.74	<0.11	0.39	0.14	0.10
Screened Solids	11.3	2.30	0.43	0.72	<5	1.22	0.31	0.07
Screened FDE	1.8	0.81	0.16	0.68	<0.11	0.36	0.12	0.08

11.14 Case study 14

Location:	Te Awamutu, Waikato
Effluent type:	Scraped solids from feed pad
Farm size:	200 ha
Herd size:	800 cows
Imported feed:	1.9 t DM/cow (maize & pasture silage, PKE)
Soil order:	Allophanic/Gley
Sampling date:	March, 2010

This farm has a large feed pad (95 m x 17 m) to feed supplements to the 800 cow herd (Photo 32). The pad is scraped uphill daily to a solids storage bunker (10 m x 17 m) (Photo 33). The feed pad is flood washed with green water (recycled effluent from second pond) on a daily basis. The solids are applied to a dairy support unit adjacent to the milking platform using a muck spreader. As the solids storage bunker was nearly full there was the opportunity to collect samples from earlier scrapings and estimate the time stored based on position in the bunker (Table 36).

Table 36: Chemical composition (kg/t) of scraped feed pad solids.

Sample	DM %	Total N	Min N	Total P	K	Total S	Org. C %	C/N ratio	% Min-N

Fresh	26.8	7.44	0.48	1.17	8.50	-	8.9	12	6
Fresh	20.2	4.38	0.08	0.88	2.62	0.42	6.6	15	2
>1 mth	28.5	6.13	0.29	1.57	5.40	0.96	7.4	12	5
>3 mth	35.4	6.85	0.20	1.62	9.65	1.07	12.5	21	3
>6 mth	38.2	6.58	0.28	1.61	13.2	1.10	10.7	18	4
Average	**29.7**	**6.24**	**0.27**	**1.37**	**7.87**	**0.89**	**9.2**	**15**	**11**

Photo 32: Cows on feed pad with scraped solids in foreground.

Photo 33: Solids storage bunker (photo taken months after sampling).

11.15 Case study 15

Location:	Winton, Southland
Effluent type:	Wintering barn slurry
Farm Size:	242 ha
Herd Size:	620
Soil Order:	Gley
Sampling date:	November 2009

This 242 ha dairy farm in Southland carries 620 cows. 500 dairy cows are wintered on site with a large European style wintering barn (Photo 34). The wintering barn is also used to extend the period of lactation of late calving cows. All deposited animal excreta is systematically removed from a concrete floor with rubber scrapers on a moving chain and then pumped from a collection sump into a 3,750 m^3 slurry storage pond (Photo 35). The slurry is then removed by the farmer during two targeted applications (one in spring and one in summer) and applied to a 40 ha silage block which provides feed to the wintering barn as cut and carry pasture. The slurry is removed from the pond while being stirred to create a homogenous product and applied using a 14 m^3 slurry tanker (Photos 36 & 37).

Photo 34: Interior view of the wintering barn.

Photo 35: Wintering barn and effluent storage pond with tractor mounted stirrer.

Table 37: Slurry composition (kg/m^3) of scraped wintering barn slurry.

Sample	DM %	Total N	Min N	Total P	K	Total S	Org. C %	C/N ratio	% Min-N
1	8.6	3.3	1.5	0.9	4.4	0.5	3.4	10.3	44
2	7.7	3.1	1.4	0.7	4.2	0.4	3.1	10.0	45
3	7.9	3.1	1.4	0.9	4.5	0.4	3.2	10.3	46
Mean	**8.1**	**3.2**	**1.4**	**0.8**	**4.4**	**0.4**	**3.2**	**10.2**	**45**

Slurry composition results (Table 37) suggest the applied product was homogenous in nature with high K content as a result of the collection of animal urine as well as dung. The wintering barn slurry was diluted in nutrient concentration and dry matter content as a result of the slurry pond storage being exposed to natural rainfall (approx. 1040 mm/yr) The farmer estimated the slurry would be applied at a rate of 20 m^3/ha. The measured application loading from field collection trays was 11.9 m^3/ha, equivalent to a mean depth of approximately 1.2 mm.

Photo 36: Slurry spreading pattern being measured.

Photo 37: Rear delivery spreading pattern from slurry tanker.

Figure 17 shows that the spreading distribution pattern from the slurry tanker was slightly uneven and variable with an application range from 2.9 mm to 0.5 mm application depth. The UQD uniformity was 1.76 for the slurry tanker indicating some variability; as heavier rates were applied to the left it is likely that the splash plate was slightly off centre.

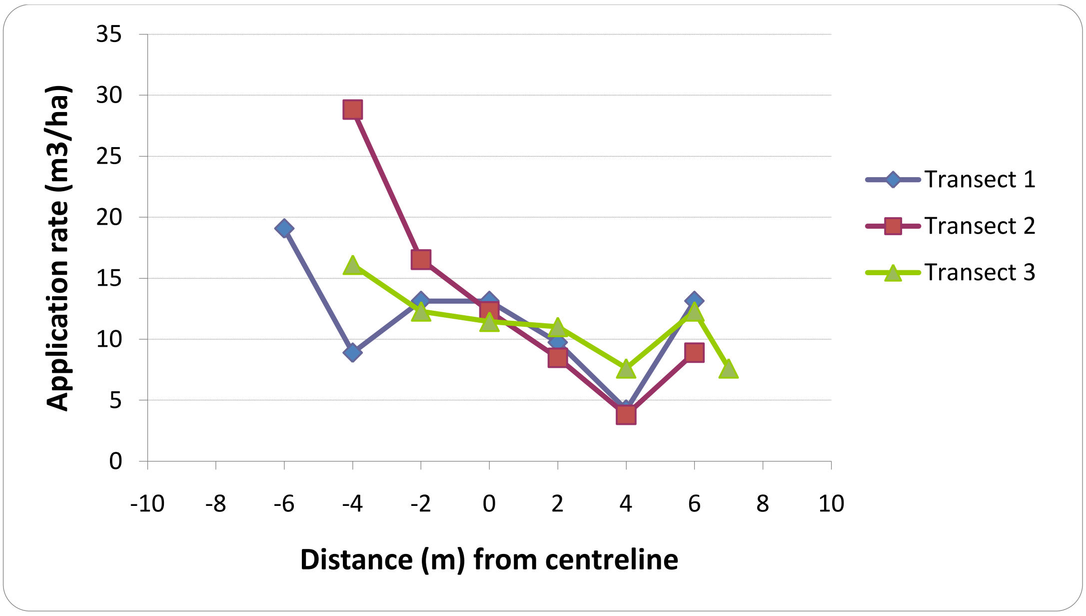

Figure 17: Application rates of liquid effluent applied from slurry tanker.

The average total load of nutrient applied to the silage pasture paddock per pass was:

- N = 38 kg/ha
- P = 10 kg/ha
- K = 52 kg/ha
- S = 5 kg/ha

The maximum N loading rate was measured at 214 kg ha^{-1}. The mean number of *E.coli* in the effluent was 2.4 x 10^8 MPN per 100mL.

11.16 Case study 16

Location:	Browns, Southland
Effluent type:	a) Mechanically separated solids (from FDE) b) Calf raising pad litter
Herd Size:	200
Soil Order	Gley
Sampling date:	November 2009

Mechanical separation of the FDE is undertaken using a screw press separator (Photo 38). The FDE is pumped from a sump to the separator. After going through the separator the liquid fraction is pumped into a storage pond and then irrigated onto an effluent block through low application rate sprinklers. The fresh solids fraction drops into a concrete bunker (Photo 39) and is occasionally removed to a nearby location for storage, until there is sufficient volume for application with a muck spreader. As the product ages the percentage of dry matter drops and it becomes darker as it starts to compost. Dry matter content starts at about 48% when fresh whilst twelve month old manure had decreased to approximately 17%.

Photo 38: Screw press solids separator on raised platform above solids bunker.

Photo 39: Mechanically separated solids in storage bunker.

There was a small amount of old silage mixed with the screw press effluent as a convenient means of disposal. A deep carbon bed is used for raising calves on the property. The carbon source was bark and wood chips replaced with fresh material each year. Spreading of both effluent types took place with a tractor pulled muck spreader containing 4 vertical rotating augers at the rear. It had a swath width of approximately 12m. The paddock that received both waste types was subsequently cultivated and returned to pasture. Figures 18 and 19 below show the distribution pattern from the muck spreader for the solid fraction of the mechanically separated effluent and the calf bedding litter.

Table 38: Chemical composition (kg/t) of fresh screw press solids.

Sample	DM %	Total N	Min N	Total P	K	Total S	Org C %	C/N ratio	% Min-N
1	29.5	5.8	0.0	1.0	1.9	0.6	10.6	18.3	0.5
2	39.8	5.6	0.0	1.1	2.3	0.8	11.4	20.3	0.7
3	36.1	7.0	0.0	1.1	2.8	1.0	13.1	18.8	0.0
Mean	**35.1**	**6.1**	**0.0**	**1.1**	**2.3**	**0.8**	**11.7**	**19.2**	**0.4**

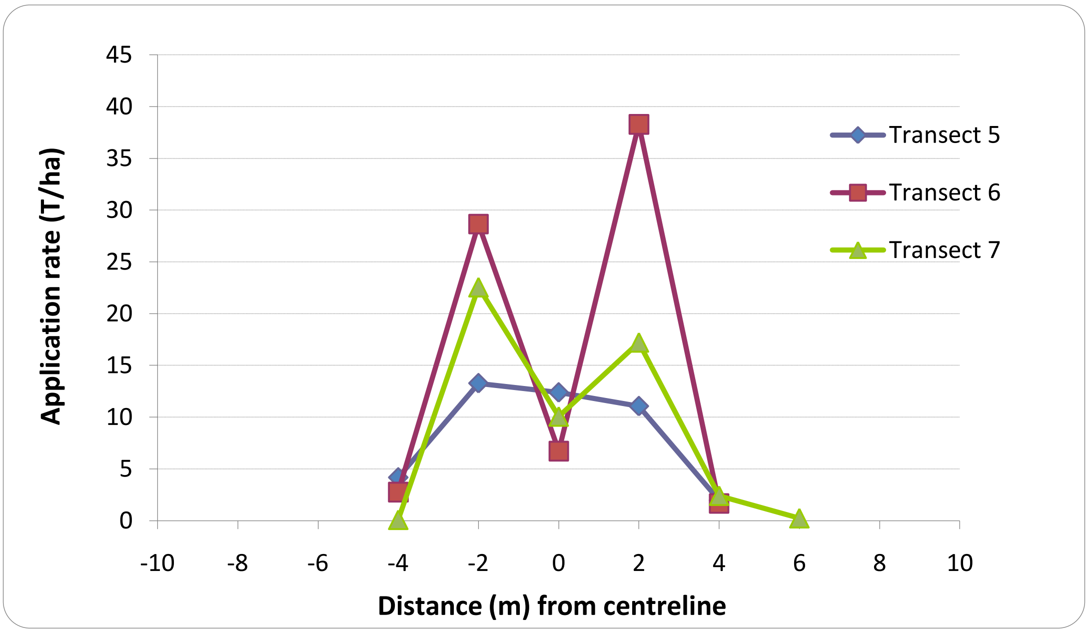

Figure 18: Application rates of mechanically separated solids applied from muck spreader.

The screw press worked very efficiently to remove moisture and liquid from the manure; a very dry solids product was obtained (Table 25). The amount of fresh material applied to the pasture was approximately 11t/ha. The average total nutrient loading applied to the silage pasture paddock per pass was:

- N = 66 kg/ha
- P =12 kg/ha
- K = 26 kg/ha
- S = 9 kg/ha

The maximum N loading rate was measured at 87 kg/ha. The mean number of *E. coli* in the solids was 9.6 x10^8 per 100g.

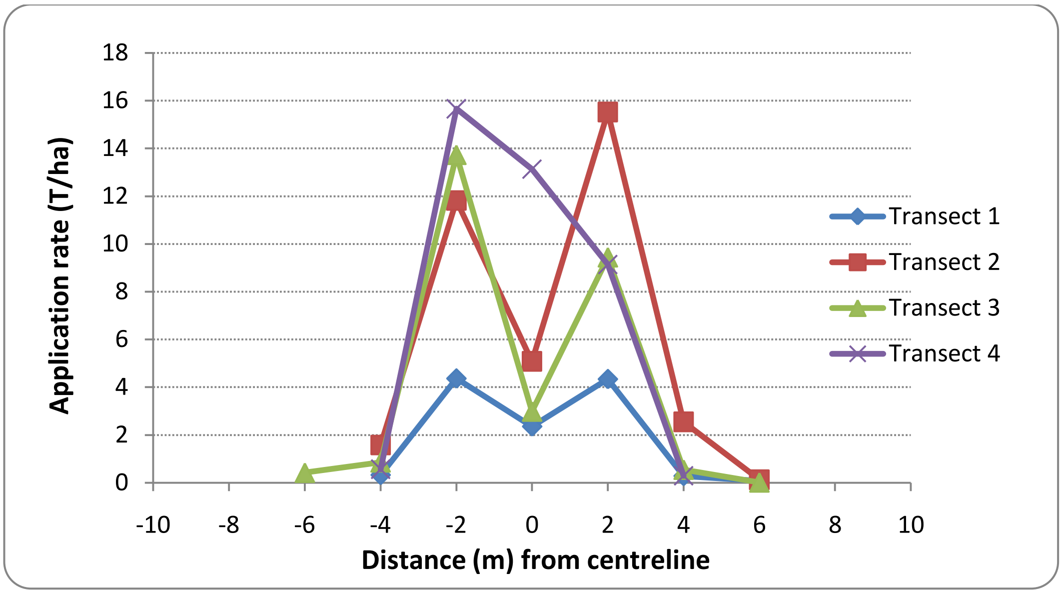

Figure 19: Application rates of calf bedding litter applied from muck spreader.

The bark and wood chips from the calf rearing pad was also a very dry product, so spread reasonably well. The UQD uniformity was 2.19 for the screw press and 1.85 for the calf pad litter. Table 39 below shows the composition of the solid waste of the calving bed litter.

Table 39: Chemical composition (kg/t) of calving bed litter.

Sample	DM %	Total N	Min N	Total P	K	Total S	Org C %	C/N ratio	% Min-N
1	48.7	3.1	0.8	0.8	1.9	0.4	23.3	74.7	26.2
2	48.6	1.9	0.6	0.6	1.3	0.2	22.3	119.9	33.6
3	50.2	2.8	0.8	1.0	1.9	0.4	22.0	78.6	26.8
4	47.6	3.0	1.0	1.1	2.6	0.7	17.2	57.0	31.9
Mean	**48.8**	**2.7**	**0.8**	**0.9**	**1.9**	**0.4**	**21.2**	**82.5**	**29.6**

The amount of calving pad litter applied to the pasture was approximately 5 t/ha (Photos 40 & 41). The solids content of the calf rearing pad litter was very high at 49% DM (Photo 42). The average total nutrient loading applied to the silage pasture paddock per pass was:

- N = 13 kg/ha
- P = 4 kg/ha
- K =10 kg/ha
- S = 2 kg/ha

The maximum N loading rate was up to 47 kg/ha. The mean number of *E. coli* in the calving bed litter was 9.1 x10^8 per 100g.

Photo 40: Loading stockpiled calf rearing pad litter.

Photo 41: Spreading of calf rearing pad litter.

Photo 42: Solid fraction remaining after going through mechanical screw press separator (fresh and old solids visible).

11.17 Case study 17

Location:	Clutha, South Otago
Effluent type:	Weeping wall dry bed solids
Farm Size:	234 ha
Herd Size:	650
Soil Order:	Pallic
Sampling date:	Jan 2010

Effluent from the dairy shed travels down to a stone trap/sump (Photo 43) and then is pumped up to one of two weeping walls. The weeping walls are used alternately, so one is used while the other is dried out, it is then emptied, ready for further use. Liquid from the weeping wall is pumped into a storage pond and then pumped out onto pasture via a low rate sprinkler irrigation system. Effluent samples were collected from the stone trap and the liquid and solid content including their chemical composition was analysed (Table 40). The "mid" and "late" season samples were collected from stockpiled solids after excavation from the dairy stone trap by front-end loader. The "fresh" sample was from in situ solids allowed to drain before laboratory submission.

Photo 43: Sand/stone sump with raw FDE.

Table 40: Analyses (kg/t) from sand/stone trap effluents.

Sump solids	DM %	Total N	Min N	Total P	K	Total S	Org C %	C/N ratio	% Min-N
Stored solids									
Late season	29.5	1.7	0.1	0.5	1.3	0.8	4.0	24	6
Mid season	26.3	2.9	0.3	0.7	1.2	1.2	30.3	105	10
Fresh	36.5	1.4	0.1	0.7	1.3	0.9	3.7	26	7
Mean	**30.8**	**2.0**	**0.2**	**0.6**	**1.3**	**1.0**	**12.7**	**52**	**8**
Fresh FDE	0.2	0.1	0.0	0.0	0.2	0.0	<0.1	0.0	36

The weeping wall solids are dried for several months before emptying and then an excavator is used to remove all the dried manure. The solids are loaded into a tractor pulled Orbital muck spreader and spread onto pasture that is used for silage making. The spreader has a manure capacity of 10-12 m^3 and throws to one side only, covering a distance of up to 20 m. The weeping wall manure has a thick dry crust on top and gets wetter further down the profile. As it is removed it gets reasonably well mixed and homogenised. The spread product has a thick slurry type consistency with a dry matter of about 38%. The UQD uniformity was 2.05 for a single pass. The coverage was variable in places, however overlapping of passes helped to get a more even coverage overall (Figure 20). The chemical composition of the weeping wall solids is presented in Table 41.

Table 41: Chemical composition (kg/t) weeping wall solids.

Sample	DM %	Total N	Min N	Total P	K	Total S	Org C %	C/N ratio	% Min-N
1	28.3	2.2	0.2	0.5	1.0	0.7	15.0	69.1	7.9
2	38.4	1.3	0.1	0.4	1.3	0.5	6.9	52.7	5.3
3	47.0	1.7	0.1	0.6	1.3	1.2	9.3	54.1	4.1
Mean	**37.9**	**1.7**	**0.1**	**0.5**	**1.2**	**0.8**	**10.4**	**58.6**	**5.8**

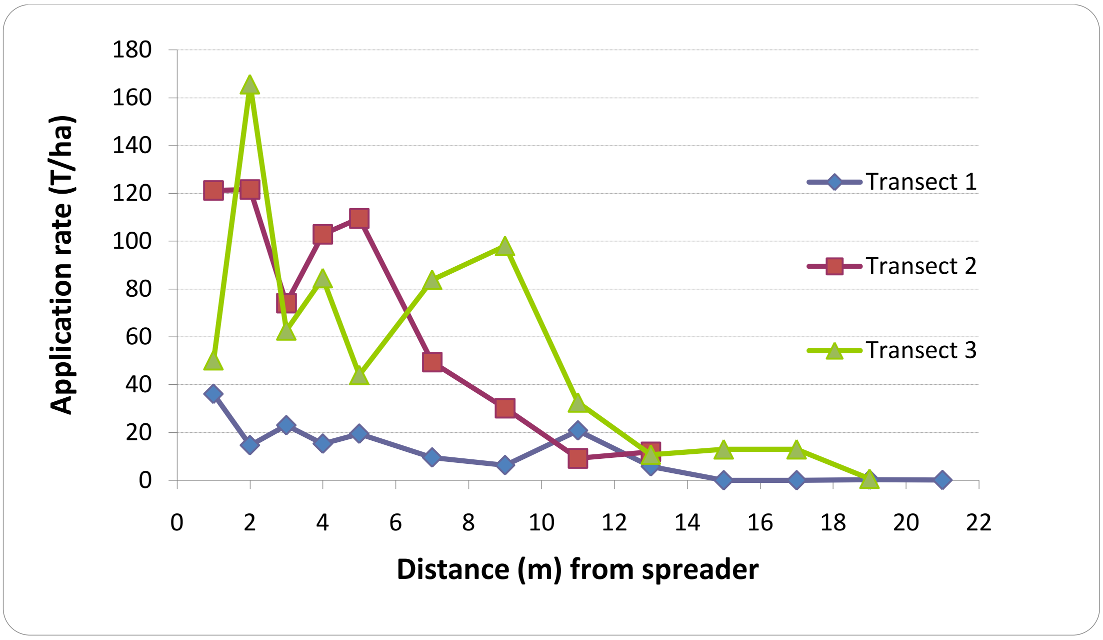

Figure 20: Distribution pattern of manure applied from orbital muck spreader.

The amount of fresh material applied to the pasture was approximately 45 t/ha. The average total load of nutrient applied to the silage pasture paddock per pass was:

- N = 72 kg/ha
- P = 22 kg/ha
- K = 59 kg/ha
- S = 36 kg/ha

The maximum N loading rate was measured at 205 kg/ha. The mean number of *E. coli* in the solids manure was 4.5 x 10^{5} MPN per 100g.The manure was difficult to transport as it was still rather liquid below the surface crust (Photos 44 & 45). That meant that more loads were required as the spreader could not be filled to capacity or it would spill out. The excavator operator also needed to be careful not to damage the clay base of the beds and cause leakage issues in the future.

Photo 44: Excavator removing manure from the weeping wall.

Photo 45: Solid manure being removed from behind the weeping wall.

The paddock receiving the solids (Photos 46 & 47) had previously been sprayed with herbicide, in preparation for cultivation. The paddocks will be re-grassed several weeks after the application of the weeping wall manure.

Photo 46: Application of manure from orbital muck spreader.

Photo 47: Solids on pasture after application.

11.18 Case study 18

Location:	Otahuti, Southland
Effluent type:	Weeping wall solids separation
Herd Size:	600
Soil Order	Pallic
Sampling date:	January 2010

The FDE is pumped into a weeping wall about 35m long and 5.5 m wide. There are two weeping walls and they are used alternately. When one is full the other can be used allowing the first to dry out in preparation for spreading. The weeping walls allow liquid to pass though into a storage pond and then this is pumped out through a low rate sprinkler irrigation system onto pasture (Photo 48). The weeping wall solids are excavated, put into dump trucks, then transported to the target paddock and dumped in lines. A tractor pulling a 6m wide leveller goes over the top of the lines and flattens them out and spreads the effluent. Several passes in different directions are made over the area (Photos 49 & 50). The slurry from the weeping walls was quite wet so tended to smear over the grass. The paddock receiving the effluent was already in pasture and it was used as a direct fertiliser to increase grass growth. The grass is able to push through the applied slurry and continue growing. According to the farmer, rain in the days following application helps this process and reduces a hard dry crust forming.

Photo 48: Weeping wall solids with liquid draining to effluent storage pond.

Photo 49: Tractor pulling the leveller to spread manure.

Photo 50: Pasture after manure spread by leveller.

An agricultural contractor was used for the excavation and dump trucking of solids but the farmer already had the leveller and tractor so didn't need to hire a muck spreader. The paddock receiving the solids had good coverage (Photo 51) but there was some variability in the amount applied to specific areas (Figure 21). The UQD uniformity was 1.97. The chemical composition of the weeping wall solids is presented in Table 42.

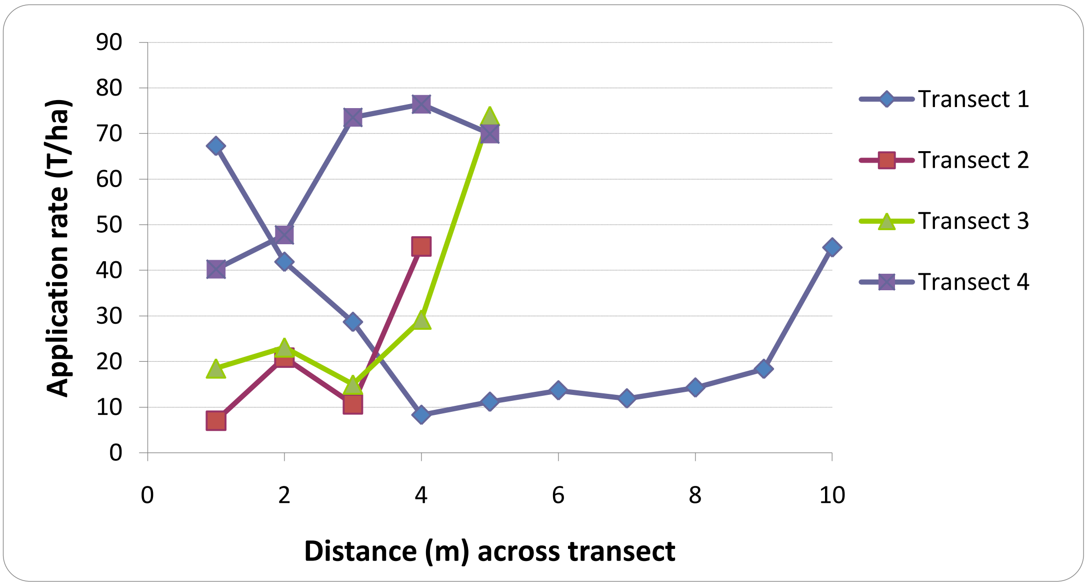

Figure 21: Application rates of weeping wall solids applied after being spread and leveled.

Table 42: Chemical composition (kg/t) of weeping wall solids.

Sample	DM %	Total N	Min N	Total P	K	Total S	Org C %	C/N ratio	% Min-N
1	24.7	3.5	0.4	0.9	1.0	0.7	4.4	12.5	11.6
2	19.2	3.7	0.5	0.7	0.9	0.7	5.1	13.8	12.3
3	29.3	4.1	0.4	0.8	1.3	0.6	5.0	12.2	10.0
4	21.8	3.8	0.4	0.8	1.1	0.7	6.0	15.9	11.7
Mean	**23.8**	**3.8**	**0.4**	**0.8**	**1.1**	**0.7**	**5.1**	**13.6**	**11.4**

The amount of fresh material applied to the pasture was approximately 35 t/ha. The average total load of nutrient applied to the silage pasture paddock per pass was:

- N = 133 kg/ha
- P = 29 kg/ha
- K = 38 kg/ha
- S = 24 kg/ha

The maximum N loading rate was measured at 303 kg/ha. The mean number of *E. coli* in the manure was 2.4 x10^6 MPN per 100g.

Photo 51: Paddock after several passes of the tractor pulled leveller.

11.19 Case study 19

Location:	Riverton, Southland
Effluent type:	Weeping wall solids dual system
Soil Order:	Brown
Sampling date:	June 2010

FDE from shed wash down is fed into a dual weeping wall system. From the weeping wall the liquid component of the effluent is pumped into a storage pond before irrigating onto pasture. The solids left behind in the weeping wall had liquid added and then was stirred using a tractor mounted stirrer to make into wet homogenous pumpable slurry (Photo 52). A vacuum pump was used to fill a 15 m^3 slurry tanker, pulled with a tractor, which applied the slurry to a pasture paddock for its fertilising benefits (Photo 53). The slurry tanker had a rear mounted splash delivery plate (Photo 54) with a swath width of approximately 12 m.

Photo 52: Weeping wall bed with liquid added. A tractor mounted stirrer (right) and slurry tanker (left) pumping out the bed with a vacuum pump

Photo 53: Slurry tanker applying effluent to pasture.

Photo 54: Rear delivery splash plate on the slurry tanker.

Spreading distribution results for applied slurry are presented in Figure 22. At the time of spreading there was a small amount of overlap with passes, to ensure the visible coverage appeared even without any uncovered areas. The amount of fresh material applied to the pasture was approximately 15 m^3 per ha or a depth of 1.5 mm. The UQD uniformity was 2.05. The chemical composition of weeping wall slurry is presented in Table 43 and shows that the slurry was very homogeneous.

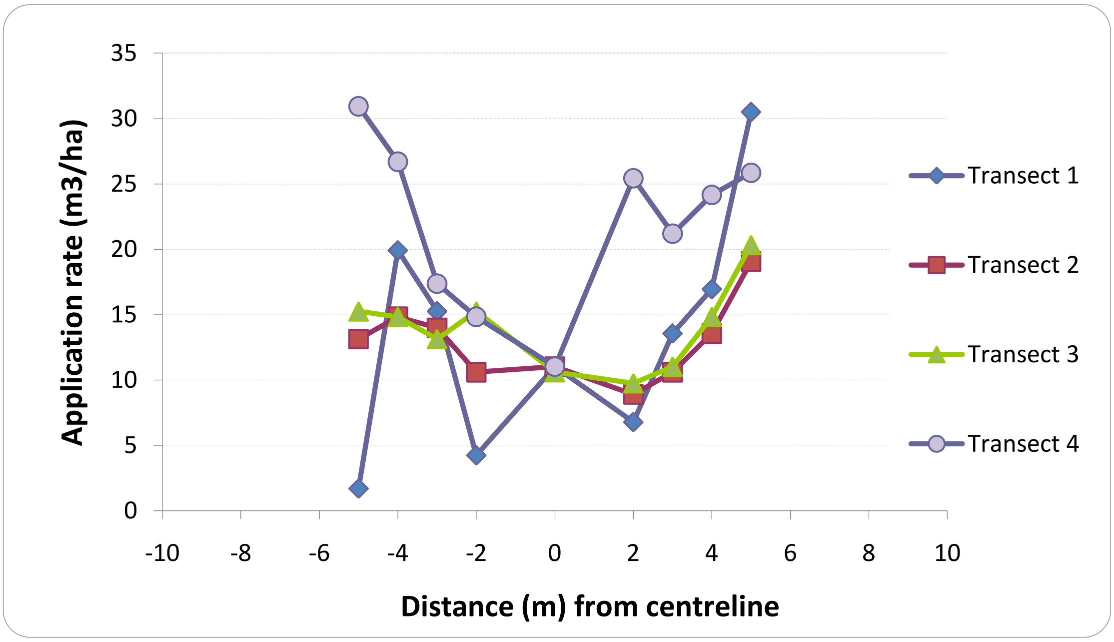

Figure 22: Application rates of liquid effluent applied from slurry tanker.

Table 43: Chemical composition (kg/m^3) weeping wall slurry.

Sample	DM %	Total N	Min N	Total P	K	Total S	Org C %	C/N ratio	% Min-N
1	11.0	1.4	0.3	0.6	0.5	0.3	21.1	15.2	20.8
2	10.7	1.5	0.3	0.6	0.5	0.3	13.4	9.5	20.4
3	10.4	1.6	0.3	0.5	0.5	0.3	20.2	13.2	20.3
4	10.3	1.7	0.3	0.5	0.5	0.4	16.3	10.3	20.0
Mean	**10.6**	**1.5**	**0.3**	**0.5**	**0.5**	**0.3**	**17.8**	**12.0**	**20.4**

The load of nutrients applied to the silage pasture paddock per pass was:

- N = 24 kg/ha
- P = 8 kg/ha
- K = 8 kg/ha
- S = 5 kg/ha

The maximum N loading rate was measured at 38 kg ha^{-1}. The mean number of *E. coli* in the effluent was 5.0x10^5 MPN per 100g.

In addition some samples were taken from these properties laneways in order to characterise the build up of sediment and muck at the entrance to the dairy shed. Each sample is derived from collecting from a 75 m transect of samples at 5 m intervals (Table 44). In summary it would appear that compared to other solid manures, lane way solids have a lower N:P ratio with much lower organic C and mineral N content. The DM% was also very high compared to other solids but this is likely to be very weather dependant. Considering the low mineral N content but relatively high P content it would appear that runoff loss of soluble P would pose the greatest environmental; risk from laneways. Suitable grass buffer areas to capture any runoff should adequately mitigate the risk of direct losses into water ways.

Table 44: Chemical composition (kg/m^3) of lane way effluent.

Sample	DM%	Tot N	Min N	Tot P	K	Tot S	Org C %	C/N ratio	% Min-N
1	55.3	2.2	0.0	1.0	1.4	0.4	2.6	11.9	0.9
2	52.6	2.3	0.0	1.2	1.1	0.5	2.7	11.7	0.8
3	55.7	2.0	0.0	1.0	1.2	0.4	2.3	11.3	0.7
Mean	**54.5**	**2.2**	**0.0**	**1.1**	**1.2**	**0.4**	**2.5**	**11.6**	**0.8**

11.20 Case study 20

Location:	Clinton, South Otago
Waste type:	Carbon based calving pad
Herd Size:	620
Feed:	Silage, hay and straw
Soil order:	Brown
Sampling date:	December 2010

Over the course of the winter about 200 cows are put onto an uncovered calving pad. They are fed on a diet of silage, hay and straw. The pad has a covering of sawdust and a bark base, which has been in place since the mid 1990's. The sawdust is removed and fresh sawdust replaced each season. The pad has a series of drains under it to capture any liquid that then runs into a pond. About 850 m^3 of sawdust is used each season.

An agricultural contractor using an excavator and dump truck removes the solids from the calving pad. The trucks dump the sawdust and dung mix onto a pasture block which is then driven over with a 6 m wide leveller pulled by a tractor. About three passes are made in different directions to get an even spread. The paddock that the manure is spread on has an additional 150 kg/ha of urea fertiliser (46% N) added and is used for cutting silage and raising wintering lambs. The distribution pattern of the solids spreading is presented in Figure 23. The UQD uniformity was 1.87. It must be noted that these measurements were taken after a single pass of the leveller, so the spreading distribution after another two passes would likely provide greater uniformity. Table 45 presents chemical analysis of the calving pad solids. The very low mineral-N % indicates these solids should be considered very slow release manure. The high C:N ratio may also influence soil N immobilisation at the time of application.

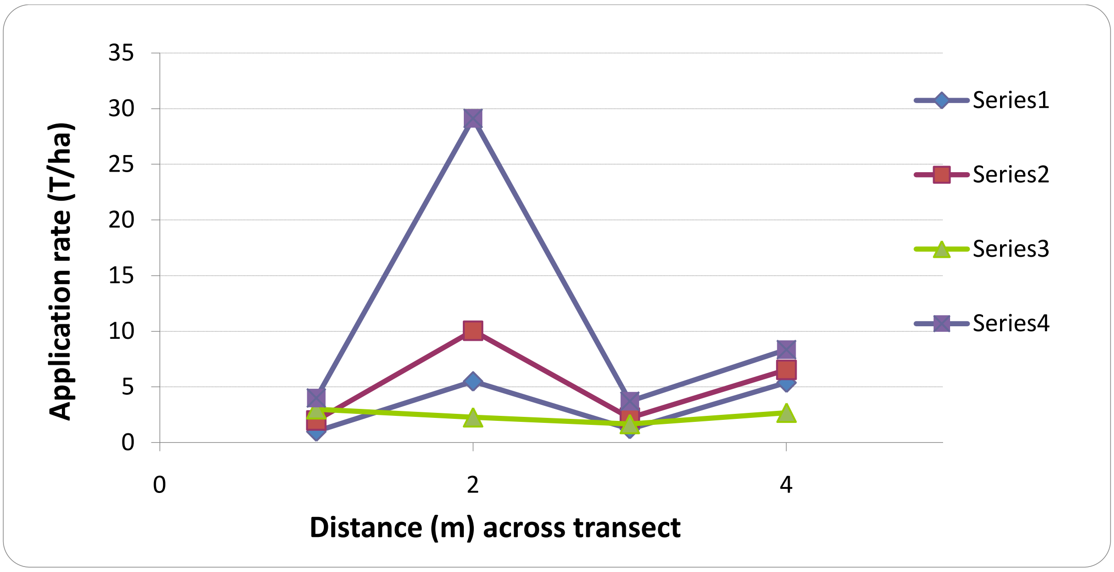

Figure 23: Application rates of calving pad solids after spreading using a leveler.

Table 45: Chemical composition (kg/t) of calving pad solids.

Sample	DM %	Total N	Min N	Total P	K	Total S	Org C %	C/N ratio	% Min-N
1	37.0	2.7	0.1	0.7	2.3	0.3	15.8	58.5	0.4
2	41.8	3.0	0.1	0.9	2.8	0.4	17.8	59.3	0.3
3	36.9	2.8	0.1	0.6	2.1	0.3	16.6	59.3	0.4
Mean	**38.6**	**2.8**	**0.1**	**0.7**	**2.4**	**0.3**	**16.7**	**59.0**	**0.4**

The amount of fresh material applied to the pasture was approximately 6.5t/ha. The average total load of nutrients applied to the silage pasture paddock per pass was:

- N = 18 kg/ha
- P = 5 kg/ha
- K = 15 kg/ha
- S = 2 kg/ha

The maximum N loading rate was 78 kg/ha. The mean number of *E. coli* in the calving pad solids was 1.4 x10^5 MPN per 100g. The removal and spreading of solids seemed to work reasonably efficiently. At the time it seemed quite chunky, however, three weeks later the paddock had recovered very well and grass had grown over and covered most of the wood chips (Photo 55).

Photo 55: Pasture recovery three weeks after application of the calving pad manure.

11.21 Case study 21

Location:	Warepa, South Otago
Effluent type:	a) Beef Wintering HerdHomes® Shelter bunker solids
	b) Beef Wintering HerdHomes® Shelter liquids
Farm Size:	77ha
Herd Size:	200 Beef cattle (various ages)
Imported feed:	Palm kernal, pasture silage
Soil order:	Pallic
Sampling date:	November 2009

Using a HerdHomes® Shelter is a novel way of raising beef to protect pastures during wet winter periods while increasing liveweight weight gains. This South Otago beef unit raises mainly Friesian steers from bobby calves. Up to 190 cattle are housed in the 60 m x 10 m animal shelter during the winter from April though until August. The numbers of cattle using the facility changes during the winter with the peak 100% capacity during June. The concrete slatted floor is covered with straw for a bedding material and also for fibre (Photo 56). The cattle are fed mainly pasture silage with a ration of supplementary palm kernel.

Photo 56: Beef cattle on straw covered slatted floor of HerdHomes® Shelter.

The manure and straw is captured in a 1.6 m deep bunker and removed once per year. Liquid from the bunker is drained into an uncovered storage pond. This is removed and spread by a 6.5 m^3 vacuum slurry tanker with a rear mounted splash plate. The bunker manure, which has a thick reasonably dry consistency (21% DM) is removed with a tractor mounted loader and put into a 12 t orbital muck spreader. Both the liquid and solid manure are spread on pasture. The effluents were applied as a fertiliser to increase growth rates of the existing pasture cover.

The orbital muck spreader throws only to one side covering an area up to a distance of about 20 m. Figure 24 presents the spreading distribution pattern of the solid waste from the muck spreader. As the oribtal muck spreader has a side delivery system (Photo 57), and given the consitancy of the HerdHomes® Shelter manure, the spreading tended to be in bigger pieces rather than small even sized pieces (Photo 58). The UQD uniformity was 2.5, which shows the rather large variability in the spread. The HerdHomes® Shelter manure was reasonably solid and held together well. It requires some effort and skill to remove the grates from the the HerdHomes® Shelter, and good timing is needed between spreader and loader operator to ensure no wasted time.

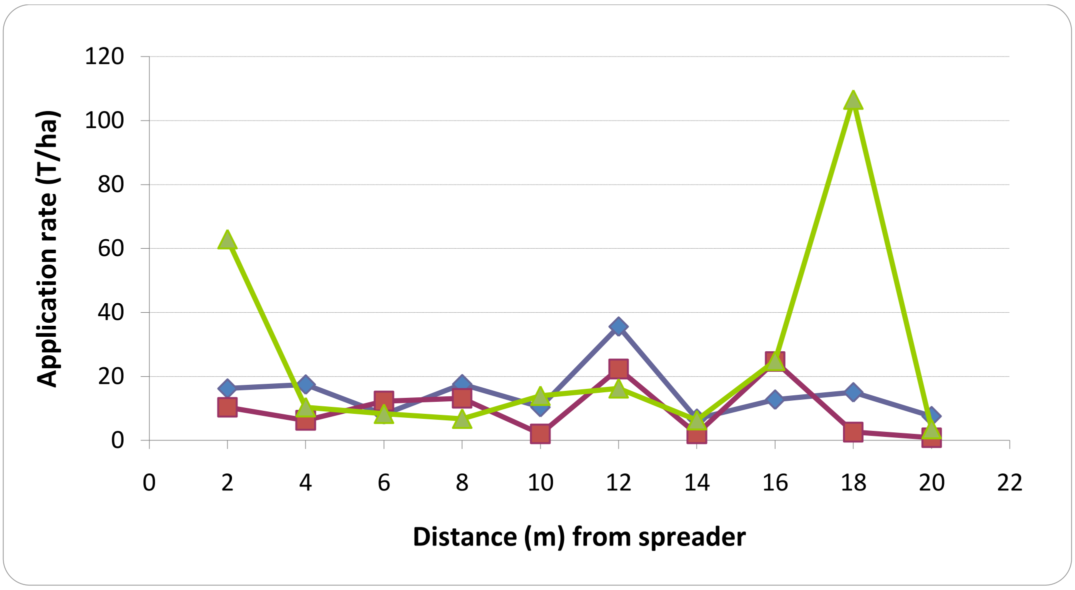

Figure 24: Application rates of HerdHomes® Shelter solid manure applied from orbital muck spreader.

Photo 57: Side delivery of solids from orbital muck spreader.

Photo 58: Pasture after spreading bunker solids showing clumpy distribution.

The chemical composition of the HerdHomes® Shelter bunker manure is presented in Table 46 and shows it to be reasonably uniform material.

Table 46: Chemical composition (kg/t) of HerdHomes® Shelter bunker manure.

Sample	DM %	Total N	Min N	Total P	K	Total S	% Min-N
1	21.5	7.4	1.8	1.8	8.4	0.8	23.5
2	21.9	7.4	1.8	1.9	8.1	1.0	24.5
3	20.9	7.1	1.6	1.7	8.4	0.8	22.2
Mean	**21.4**	**7.3**	**1.7**	**1.8**	**8.3**	**0.9**	**23.4**

The amount of HerdHomes® Shelter bunker solid applied to the pasture was approximately 16.8 t/ha. The average total loading of nutrients applied to the silage pasture paddock per pass was:

- N = 122 kg/ha
- P = 30 kg/ha
- K = 140 kg/ha
- S = 14 kg/ha

The maximum N loading rate was measured at 757 kg/ha. The mean number of *E. coli* in the manure was 9.7x10^4 MPN per 100g.

The drained liquid was stored in the holding pond (Photo 59) and it is a relatively quick and easy job to remove this with a hose and vacuum pump and then apply via slurry tanker (Photo 60). Distribution of effluent could be affected by wind drift so application is best in calm conditions. The UQD uniformity for the liquid component was 1.63 and the distribution of the spreading can be seen in Figure 25. The chemical composition of weeping wall slurry is presented in Table 47. The drained liquid is very K-rich and % mineral-N indicates that 62% of Total N is plant available.

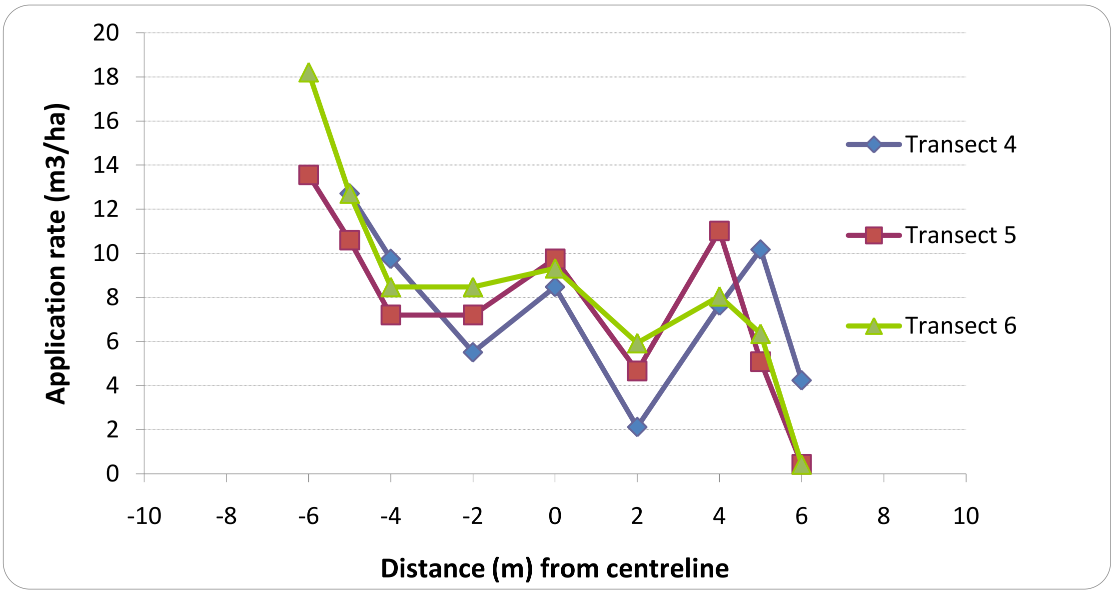

Figure 25: Application rates of liquid effluent applied from slurry tanker.

Table 47: Chemical composition (kg/m^3) of drained liquid from HerdHomes® Shelter.

Sample	DM %	Total N	Mineral N	Total P	K	Total S	% Min-N
4	2.2	1.44	1.03	0.17	4.68	0.14	72
5	1.6	0.75	0.41	0.10	4.00	0.10	55
6	1.6	0.56	0.34	0.11	3.83	0.10	60
Mean	**1.8**	**0.92**	**0.59**	**0.13**	**4.17**	**0.11**	**62**

The amount of effluent applied to the pasture was approximately 8m^3/ha or 0.79 mm depth. The average total load of nutrient applied to the silage pasture paddock per pass was:

- N = 7 kg/ha
- P = 1 kg/ha
- K = 32 kg/ha
- S = 1 kg/ha

The maximum N loading rate was measured at 19 kg/ha. The mean number of *E. coli* in the effluent was 1.8 x10^4 MPN per 100mL.

Photo 59: Pond for drained liquid from HerdHomes® Shelter.

Photo 60: Land application via slurry tanker.

11.22 Case study 22

Location:	Inchclutha, South Otago
Waste type:	Manure and woodchip/bark manure from wintering barn
Herd Size:	400
Feed:	Silage
Soil order:	Recent
Sampling date:	March 2010

150 cows are wintered in a covered shed with a bark/sawdust bed approximately 0.5 m deep. The deep litter wintering shed utilised an existing shed already on the farm. At the front of the wintering shed is an uncovered concrete feeding pad. Each season the shed is emptied of its base material and the accumulation of three months of dung, urine and bedding. Bedding is replaced with fresh sawdust and bark. The spent material is then removed from the shed with a loader and put into a muck spreader, which has a capacity of 8-10m^3 and a swath width of 14m. It has two rotating drums that eject material at the rear onto paddocks recently cut for baleage. Three to four weeks after solids application the paddock will be grazed by yearlings. The UQD uniformity was 2.44, which indicates there is some variability in the distribution (Figure 26). Table 48 below shows the chemical composition for three samples of wintering barn solids. Low mineral-N % indicates a very slow release solid.

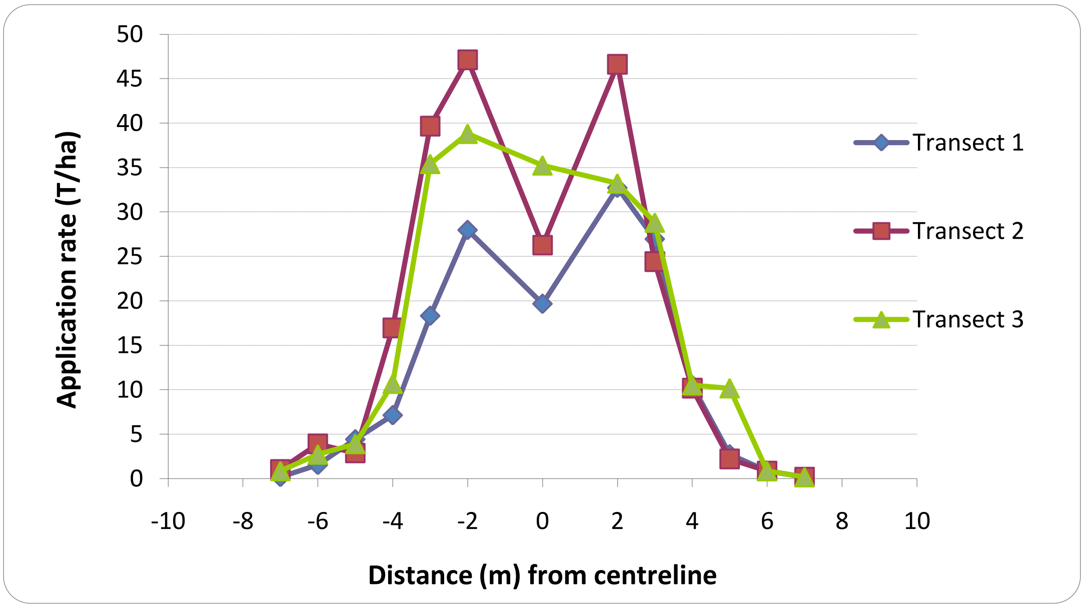

Figure 26: Application rates of solid manure applied from muck spreader.

Table 48: Chemical composition (kg/t) and the mean value of wintering barn solids

Sample	DM %	Total N	Min N	Total P	K	Total S	% Min-N
1	30.2	4.6	0.0	1.5	8.5	0.8	0.7
2	28.3	4.6	0.0	1.5	8.5	0.9	0.7
3	31.7	4.2	0.1	1.5	9.0	0.8	2.0
Mean	**30.1**	**4.5**	**0.0**	**1.5**	**8.7**	**0.8**	**1.1**

The amount of wintering barn solids applied to the pasture was approximately 15 t/ha. The average total nutrient loading applied to the silage pasture paddock per pass was:

- N 80 kg/ha
- P 22 kg/ha
- K 97 kg/ha
- S 11 kg/ha

The maximum N loading rate was measured at 218 kg/ha. The mean number of *E. coli* in the manure was 2.3 x10^6 MPN per 100g. The spreading machinery used is co-owned by 5 farmers. The cost to buy a new muck spreader is approximately $60,000 - 70,000. It appears a good idea to co-own expensive machinery to reduce manure management costs. However, there can be application problems with spreader availability due to similar farm schedules. The property also has a HerdHomes® Shelter as well with bunker manure (Table 49) which is emptied with the same equipment.

Table 49: Chemical composition (kg/t) and the mean value of HerdHomes® Shelter solids.

Sample	DM %	Total N	Min N	Total P	K	Total S	Org C %	C/N ratio	% Min-N
+ straw	17.0	5.3	1.6	1.4	6.5	0.7	6.9	13.0	30
- straw	16.6	4.9	1.2	1.6	5.0	0.7	6.9	14.1	25
Mean	**16.8**	**5.1**	**1.4**	**1.5**	**5.8**	**0.7**	**6.9**	**13.5**	**28**

12. Appendix 2: Survey of spatial variability in storage

Location:	Karapiro, Waikato
Effluent type:	HerdHomes® Shelter manure
Farm size:	60 ha
Herd size:	190 cows (winter milk)
Imported feed:	0.475 t DM/cow/yr (maize, PKE)
Soil order:	Brown/Gley
Sampling date:	March, 2011

A small Waikato dairy farm with one 60m HerdHomes® Shelter was intensively sampled to determine the spatial variability that may occur within an animal shelter. The HerdHomes® Shelter is used intensely for feeding and shelter throughout the year but especially during the May to September period. During excessively wet periods lactating cows may be housed for up to 20 hours/day but they would stay out at night if possible. The dry cows used the HerdHomes® Shelter for 22 hours/day during wet conditions. Richard Stewart, of Stockyards Ltd, has designed a tool for moving slats easily (Photo 61) plus a 30cm diameter sampling column that could be inserted to the bottom of the bunker for obtaining a manure sample. A total of 60 samples were collected (six per row across both bunkers by ten rows down length of shed) (Photo 62).

Photo 61: Concrete slats lifted to allow access for manure bunker sampling.

Photo 62: Specially designed PVC cylinder used for collecting samples. A handle at top of cylinder was used to homogenise manure within the cylinder before sampling.

Results of the chemical analysis are presented in Table 50. The mean and median values are close to each other however large variations exist between sample extremes. For example, DM varied from 7 to 44%. Upon questioning the farmer, it was learnt that solid manure material which fell outside the HerdHomes® Shelter on the concreted entry/exit area was regularly scraped to the first rows of slats in the shelter. This management practice resulted in high solids contents at the entry/exit end of the shelter and may have been the reason for the significant gradient effect throughout the shelter as presumably this action forced more liquid to the opposite end of the shelter. Contour plots illustrate the gradient effect on % DM and N concentrations throughout the shelter (Figures 27 & 28) while Figure 29 presents mean N concentrations along the length of both parallel manure bunkers.

Table 50: Chemical composition (kg/m^3) of intensive HerdHomes® Shelter bunker sampling including range (n = 60).

Sample	DM %	Total N	Min N	Total P	K	Total S	Org C %	C/N ratio	% Min-N
Mean	17.9	3.42	0.51	0.92	7.04	0.90	5.3	15.5	15
Median	17.3	3.50	0.53	0.95	7.35	0.90	5.7	16.0	15
Lowest	7.2	1.50	0.30	0.40	2.70	0.40	2.3	12.5	4
Highest	44.5	6.90	0.70	1.50	10.70	1.80	8.6	17.6	30

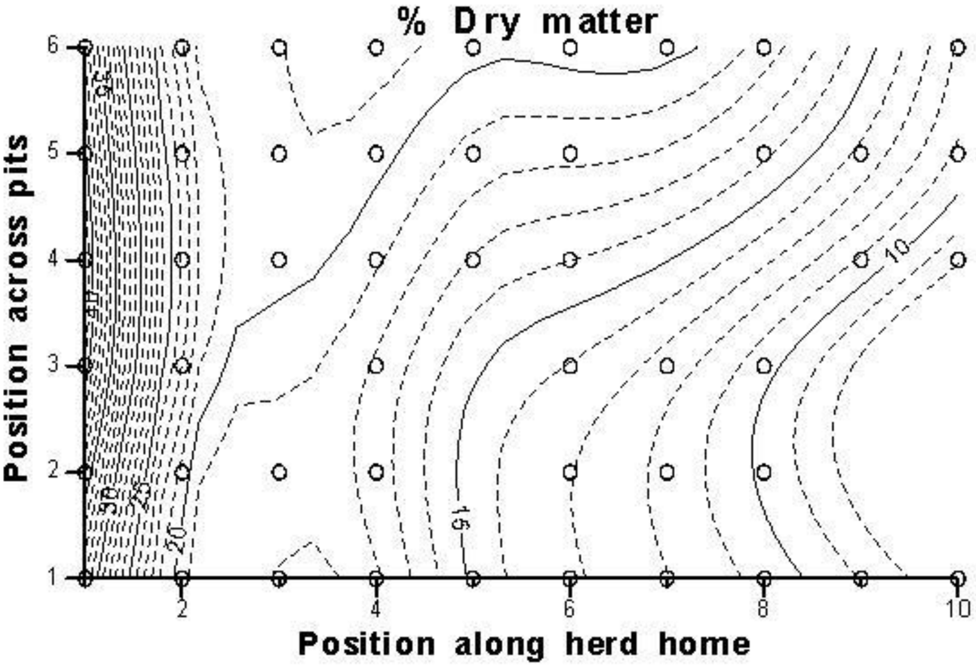

Figure 27: Contour plot illustrating solids content of manure (%DM) isolines along length of the HerdHomes® Shelter.

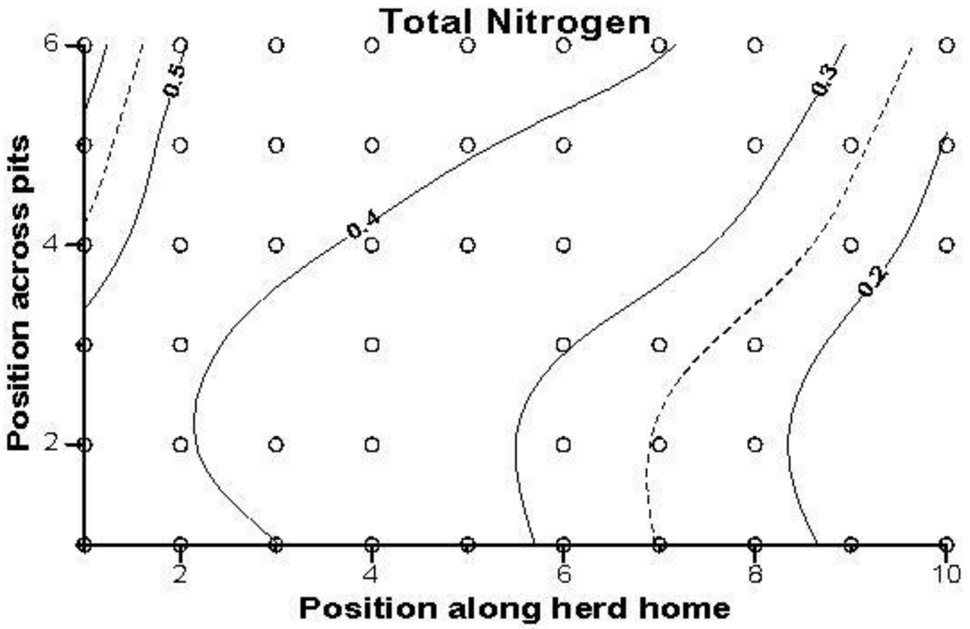

Figure 28: Contour plot illustrating nitrogen (%N) isolines of the manure along length of the HerdHomes® Shelter.

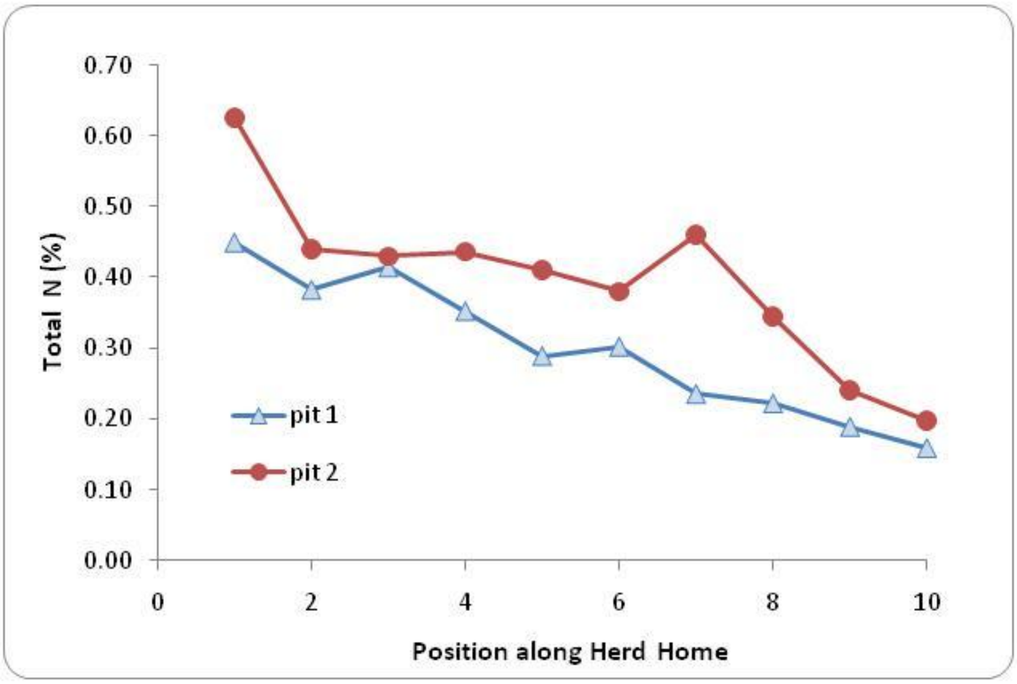

Figure 29: Nitrogen concentration (% N) in parallel bunkers along HerdHomes® Shelter.

The spatial variability of % DM and total N content demonstrates the importance of taking a sample from a well mixed source where possible. Where mixing is not possible, then a sample should be built from a composite of samples that exclude non representative areas such as HerdHomes® Shelter entrances. Carrying out more intensive survey samplings on other HerdHomes® Shelter systems to see if patterns seen here are consistent and could help determine the number of samples required to be within a known error of the true mean. In this case study sampling approx. four places in the middle of the bunkers would provide a reasonable estimate.