Assessment of Phosphorus Extraction from B.C. Dairy Manure Using a Centrifuge

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Disclaimer

The Government of Canada, the Government of British Columbia and the Investment Agriculture Foundation of B.C., are pleased to participate in the delivery of this study. We are committed to working with our industry partners to address issues of importance to the agriculture and agri-food industry in British Columbia. Opinions expressed in this report are those of Hallbar Consulting Inc. and not necessarily those of the Investment Agriculture Foundation, the Government of British Columbia or the Government of Canada.

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Acronyms & Terminology

B.C.:	British Columbia
CAPEX:	Capital costs
Cake:	Solid manure fraction produced by a centrifuge
Centrate:	Liquid manure fraction produced by a centrifuge
C:N Ratio:	Carbon to nitrogen ratio
EC:	Electrical Conductivity
GPM:	Gallons per minute
K_2O:	Potash
NMP:	Nutrient Management Plan
OPEX:	Operating costs
P_2O_5:	Phosphate
Processed Manure:	Dairy manure that has been through a solid-liquid separator
Raw Manure:	Dairy manure that hasn't been through a solid-liquid separator
RPM:	Revolutions per Minute
RFEOI:	Request for Expression of Interest
UMM:	Used mushroom media

1. Executive Summary

Some B.C. dairy farmers are experiencing a build-up of surplus phosphorus in their soils. Centrifuges, by using centrifugal force to separate solids and liquids, are capable of extracting a portion of phosphorus from dairy manure into a solid fraction. This solid fraction is called cake, the remaining liquid fraction is called centrate. This study's purpose was to assess the suitability of a centrifuge in enabling B.C. dairy farmers to reduce excess soil phosphorus levels, align with potential future nutrient management regulations, and increase herd size without having to purchase or rent additional land.

A decanting centrifuge was tested on seven dairy farms in B.C.'s Lower Mainland. Six farms have scrape manure collection, and one has flush manure collection. All seven farms have covered manure storage, use sawdust for bedding, and have solid-liquid separation technology to extract large fibre from manure for re-use as bedding. During testing the centrifuge was operated by a qualified technician at three different spin speeds (2,350 rpm, 3,500 rpm and 4,700 rpm) and feed rates (10 gpm, 20 gpm, and 25 gpm) on all seven farms. Over 300 samples of cake and centrate were collected during testing and sent to an accredited laboratory for nutrient composition analysis.

Phosphorus extraction of 50% - 60% was consistently achieved on farms with scrape collected manure, while highest extraction achieved on any farm was 75%. For flush collected manure, phosphorus extraction of 40% - 50% was consistently achieved. Typically, highest phosphorus extraction occurred when centrifuge feed rate was lowest (10 gpm) and spin speed was highest (3,500 rpm and 4,700 rpm).

During phosphorus extraction, nitrogen and potassium were also extracted. Average nitrogen and potassium extraction from scrape collected manure ranged from 27% - 61% and 25% - 63% respectively. Nitrogen and potassium extraction from flush collected manure ranged from 12% - 39% and 16% - 47% respectively. Typically, and as with phosphorous extraction, highest nitrogen and potassium extraction occurred when centrifuge feed rate was lowest and spin speed was highest.

Average solids capture from scrape collected manure was 40% - 76%, while highest capture achieved on any one farm was 92%. Solids capture from flush collected manure was 42% - 63%. Average cake dry matter from scrape collected manure was 19% - 25%, while highest dry matter achieved on any one farm was 29%. Cake dry matter from flush collected manure was 23% - 27%. Average centrate dry matter from scrape collected manure was 2% - 3%, while lowest dry matter achieved on any one farm was 1%. Centrate dry matter from flush collected manure was 2%.

Based on these results, B.C. dairy farmers with scrape collected manure should be able to extract up to 50% - 60% of the phosphorus from their dairy manure, while farmers with flush collected manure should be able to extract up to 40% - 50%[1]. At this level of phosphorus extraction, most B.C. dairy farmers should be able to reduce excess soil phosphorus levels, meet the requirements of a nutrient management plan, be in align with potential future nutrient management regulations, and even increase their herd size, without having to purchase or rent additional land.

[1] Expected phosphorus extraction is less certain for flush collected manure as testing was only done on one farm.

However, using centrifuges to extract phosphorus from dairy manure will only enable B.C. dairy farmers to reduce excess soil phosphorus levels if the cake produced by centrifuges is exported off the farm and used elsewhere. For this to occur in the Lower Mainland, and due to the current abundance of soil amendments, this cake will likely have to replace existing soil amendments, such as poultry litter, used mushroom media, horse manure or compost. When separated from dairy manure and without further processing, cake has few advantages over these soil amendments, and is therefore unlikely to replace them under present market conditions.

Value-added processing, such as composting or drying, can enable cake to have several advantages over used mushroom media, horse manure and compost; thereby making it a more desirable organic soil amendment. Depending upon type of value-added processing, these advantages can include higher nutrient content, dry matter, organic matter, and minor elements (such as boron and manganese). However, value added processing is unlikely to make cake more desirable than poultry litter; especially for horticultural operations with high nitrogen needs and already high soil phosphorous levels.

Therefore, if cake is to be widely used in the Lower Mainland, it will have to be sold at a similar or lower price than poultry litter; which is currently delivered for approximately \$5 - \$10/yard ($0.76m^3$). However, this may result in poultry litter suppliers in the Lower Mainland lowering their prices, resulting in a race to the bottom. An alternative option is to export cake to other areas of B.C., Canada, or internationally. However, the economic feasibility of doing this is currently unknown.

Centrifuges are usually installed on farms to meet nutrient management regulations. As such, they are rarely economically feasible. Instead they are seen as a cost of doing business. Despite this, it may be possible for B.C. dairy farmers to reduce costs through funding or herd expansion. However, even if funding equal to 100% of a centrifuge capital costs were available, and depending upon a dairy farm's herd size and centrifuge ownership, cake would still need to be sold for a profit of \$10 - \$58/tonne to cover operating costs. If herd size were expanded by 33% and no funding were available, cake would still need to be sold for a profit of \$5 - \$48/tonne to enable a ten year payback on investment.

Key Findings Summary:

- Centrifuges are capable of extracting a significant amount of phosphorous (typically 40% - 60%) from dairy manure into a 20% - 25% dry matter cake. Exact nutrient extraction levels largely dependent upon centrifuge feed rate and spin speed;
- If cake is exported off the farm, B.C. dairy farmers should be able to increase herd size and meet the requirements of a nutrient management plan, without increasing their existing land base;
- Centrifuges also extract nitrogen and potassium from dairy manure. B.C. dairy farmers that use centrifuges will need to purchase additional nitrogen, and possibly additional potassium;
- Because of the organic amendments available in the Lower Mainland, expected revenues from selling cake, with or without processing, will likely be insufficient to cover centrifuge costs; and
- While centrifuges are a suitable technology for addressing surplus phosphorus, they will result in additional costs for B.C. dairy farmers.

2. Introduction

Some dairy farms in B.C. produce more manure phosphorus than is required by their crops; resulting in the gradual build-up of surplus phosphorus in their soils. The reason for this excess is that large quantities of phosphorus are imported onto B.C. dairy farms in the form of feedstuffs, while smaller amounts of phosphorus is exported off the farm in the form of milk, animals, etc. Due to phosphorus build-up in some soils, an alternative to current land application of dairy manure is required by some B.C. dairy farmers.

In a recent study completed for the B.C. Ministry of Agriculture, in which the suitability of nutrient extraction technologies were evaluated, centrifuges were deemed to be appropriate for many B.C. dairy farms.[2] Centrifuges are capable of extracting phosphorus from dairy manure because most of the phosphorus is bound to small solids. By using high speeds to create centrifugal force, centrifuges separate solids from liquids; thereby extracting phosphorus from dairy manure into a solid fraction. This solid fraction is called cake. The remaining liquid fraction is called centrate.

There are several reasons why a B.C. dairy farmer might consider using a centrifuge. By extracting some of the phosphorus from dairy manure, a centrifuge can help dairy farmers reduce excess soil phosphorus levels, and enable the farm to be in alignment with potential future nutrient management regulations.[3] Furthermore, by concentrating phosphorus into cake, centrifuges can reduce the cost of transporting phosphorus between fields, and could enable dairy farmers to increase their herd size without having to purchase or rent additional land.

Today, centrifuges are widely used in many different industries to separate solids from liquids. Centrifuges are also widely used on farms in Europe, and technology adoption by farmers in the United States and Canada is increasing. Despite widespread and growing use, there are currently no centrifuges on B.C. dairy farms, and testing of centrifuges in B.C. to assess the technology's phosphorus extraction performance has been limited.

The primary purpose of this study was to test a centrifuge on several B.C. dairy farms to assess the suitability and feasibility of this technology in enabling B.C. dairy farmers to reduce excess soil phosphorus levels, align with potential future nutrient management regulations, and increase herd size without having to purchase or rent additional land. The secondary purpose of this study was to investigate different technology ownership models and how these models might benefit B.C. dairy farms, and to assess potential end markets for the cake.

3. Centrifuge Technology

Currently, there are many dairy manure nutrient extraction technologies available. Because the greatest need for most B.C. dairy farmers is to reduce excess soil phosphorus levels, the most appropriate technologies for B.C. dairy farms are those that extract sufficient phosphorus

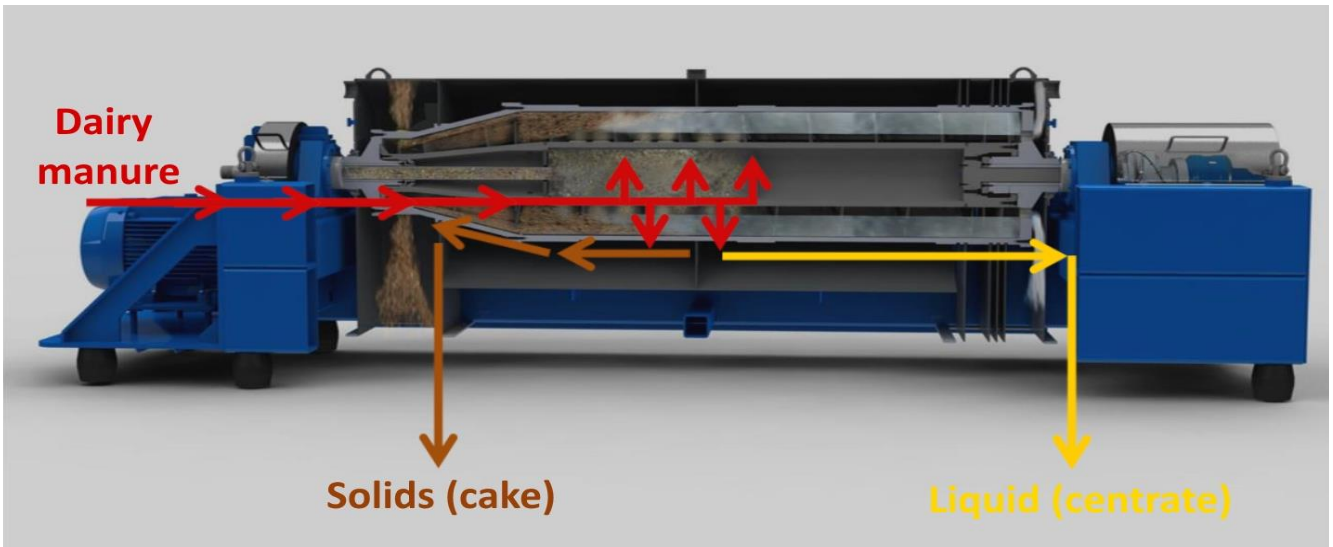
[2] Report: Evaluation of Nutrient Recovery Technologies for Dairy Manure and Digestate (2016).

[3] Currently, while there are no explicit standards in B.C. regulations for phosphorus application, changes are anticipated that will result in greater emphasis on nutrient management planning.

(approximately 30% - 60%) from dairy manure at the lowest possible cost, and without extracting too much nitrogen or potassium. Most solid-liquid separation technology currently used by B.C. dairy farmers, including screens, screw, and roller presses, extracts large fibre from manure for re-use as bedding. Because these technologies aren't specifically designed to extract phosphorus, the amount of phosphorus extracted with the bedding is typically very low (approximately 5% - 10%).

Centrifuges, unlike screen, screw, and roller presses, create centrifugal force to separate solids and liquids. Typically consisting of a horizontal bowl which continuously turns at a high velocity, centrifuges have a conveyor which rotates at a slightly different speed than the bowl; conveying cake to one end of the centrifuge for discharge, and centrate the other end (Figure 1). During phosphorus extraction, some nitrogen and potassium is also extracted.

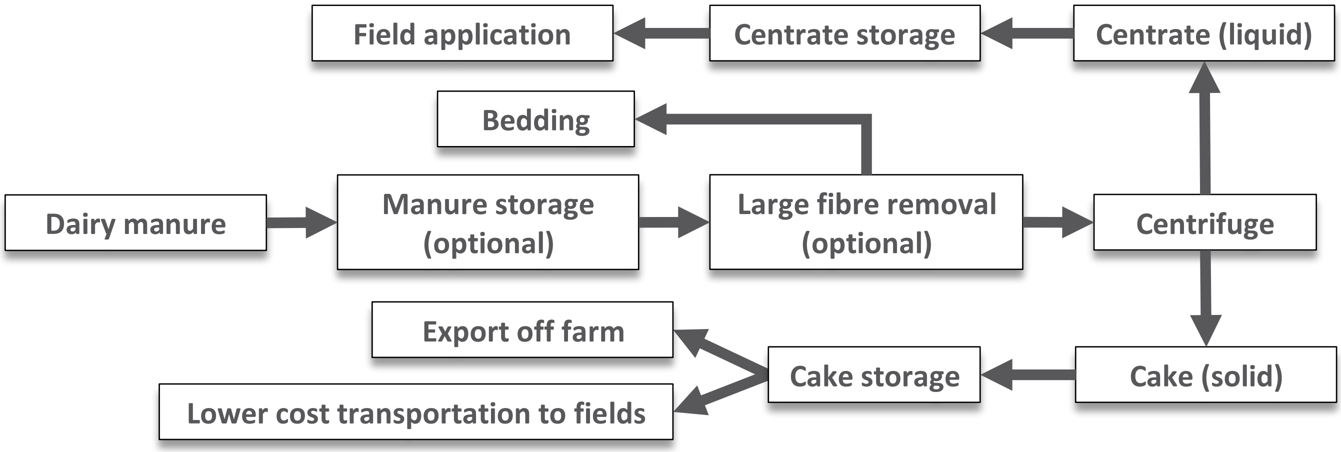
Figure 1: Example of a Typical Centrifuge



Centrifuges can integrate readily into dairy farm operations, and can be located anywhere within easy reach of manure storage. Once installed, manure is pumped to the centrifuge, possibly via solid-liquid separation that first extracts large fibre for re-use as bedding. Once separated, cake (typically 15% - 25% dry matter) can be gravity fed into a hopper or onto a conveyor for storage and then transportation to fields or exported off the farm. Centrate (typically 1 - 3% dry matter) can be pumped to storage and then field applied locally when needed by crops (Figure 2).

Powered by an electrical motor and designed to work with a continuous flow of manure, centrifuges are easily turned on or off to meet on-site manure volumes. Provided constant flow of manure, centrifuges should require little supervision or maintenance. Chemicals can be used with centrifuges to increase phosphorus extraction performance (upwards of 90%). However, these chemical can be expensive and can result in too much phosphorus being extracted for most B.C. dairy farms.

Figure 2: Centrifuge Flow Diagram for a Dairy Farm



There are several companies in North America that supply centrifuge technology for a wide variety of industries. Examples of these companies, in alphabetical order, include:

- Centrifuges Unlimited (Alberta, Canada);
- Centrisys (Wisconsin, USA);
- DariTech (Washington, USA);
- Hiller Separation (Texas, USA);
- Kubco (Texas, USA);
- Noxon (Ontario, Canada);
- Pacific Dairy Centre (BC, Canada);
- Pieralisi (Ohio, USA);
- TEMA Systems (Ohio, USA); and
- US Centrifuge (Indianapolis, USA).

All of the above mentioned companies were contacted regarding participation in this study. While all were deemed to be potentially suitable, final choice was based upon the company's experience working with dairy manure, the availability of a centrifuge that could be transported between farms, and the company's level of interest. Based on these criteria, Centrisys from Kenosha in Wisconsin was chosen.

4. Farm Selection & Testing

A Request for Expression of Interest (RFEOI) was sent to all B.C. dairy farmers through the B.C. Dairy Association. In total, eleven farmers responded to the RFEOI. Of these farms, seven were selected for this study (Figure 3). All seven farms have covered manure storage, six of the farms have scrape manure collection and one has flush manure collection. All farms have solid-liquid separation technology to extract large fibre from manure for re-use as bedding, and all farms use sawdust for bedding.[4]

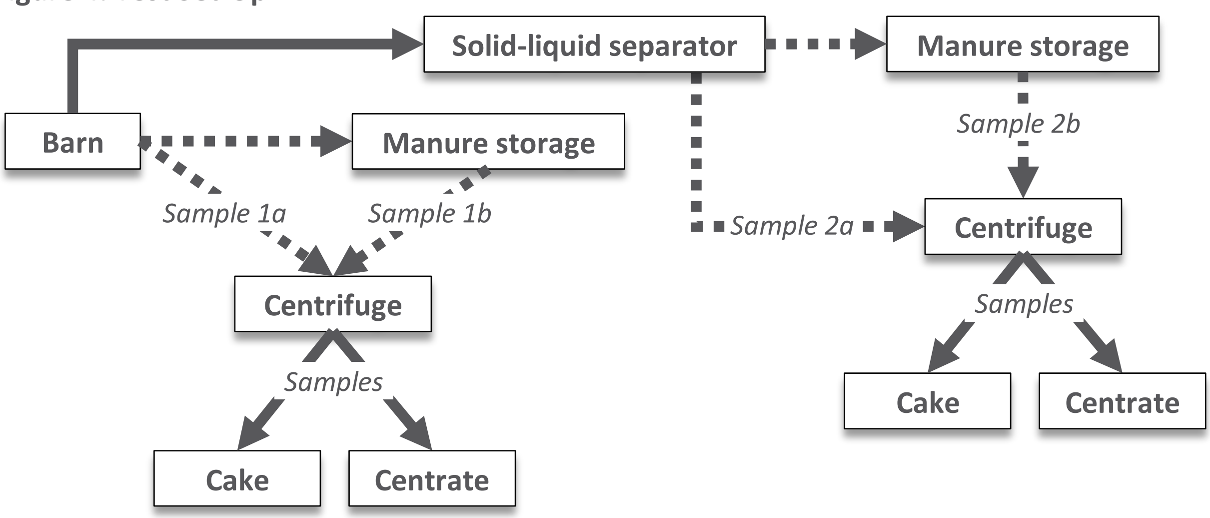
During February and March of 2017, the centrifuge was delivered to all seven farms to assess nutrient extraction performance using the farm's dairy manure, both prior to and after solid-liquid separation. For this report, dairy manure that hasn't been through a solid-liquid separator is called 'raw manure', and dairy manure that has been through a solid-liquid separator is called 'processed manure'.

[4] Centrifuges can be used on farms with sand bedding. However, this sand should be separated prior to the centrifuge.

Figure 3: Dairy Farms Selected for the Study

During testing, when the centrifuge was operated by a qualified technician, raw manure was taken from barns (1a) wherever possible, otherwise it was taken from well agitated manure storage (1b). Processed manure was taken from solid-liquid separators where possible (2a), otherwise it was taken from well agitated manure storage after solid-liquid separation (2b). All cake and centrate samples were collected directly from the centrifuge's discharge points (Figure 4). All samples were tested in triplicate for total phosphorus, phosphate, total nitrogen, ammonium, total potassium, potash, and dry matter.

Figure 4: Test Set-Up



During testing, the centrifuge was operated at three different spin speeds and feed rates (Table 1). Due to higher dry matter content, the centrifuge was unable to process 25 gpm of raw manure. The purpose for varying the centrifuge's spin speed and feed rate was to investigate nutrient extraction performance at different levels of centrifugal force (spin speed) and volumes of dairy manure (feed rate). No polymer, chemicals, or any other inputs were used during testing. All samples were tested in an accredited laboratory.

Table 1: Test Procedure

Test Procedure	Manure Type	Spin Speed	Feed Rate
Test 1	Raw Manure (prior to solid-liquid separation)	50% of maximum speed (2,350 RPM)	10 gpm
Test 2			20 gpm
Test 3		75% of maximum speed (3,500 RPM)	10 gpm
Test 4			20 gpm
Test 5		100% of maximum speed (4,700 RPM)	10 gpm
Test 6			20 gpm
Test 7*			25 gpm
Test 1	Processed Manure (after solid-liquid separation)	50% of maximum speed (2,350 RPM)	10 gpm
Test 2			20 gpm
Test 3			25 gpm
Test 4		75% of maximum speed (3,500 RPM)	10 gpm
Test 5			20 gpm
Test 6			25 gpm
Test 7		100% of maximum speed (4,700 RPM)	10 gpm
Test 8			20 gpm
Test 9			25 gpm

*Note: * Only for the dairy farm with flush collected manure.*

If a centrifuge was installed on a B.C. dairy farm, separate storage would be required for cake and centrate (in addition to current manure storage). For the purpose of this study, and because the seven participating dairy farms didn't have additional storage, all cake and centrate was returned to the farm's existing manure pits. When this pit was the same pit from which manure was drawn for the centrifuge, all centrate and cake were returned to the pit as far away as possible from the centrifuge intake pipe.

5. Centrifuge Extraction Performance

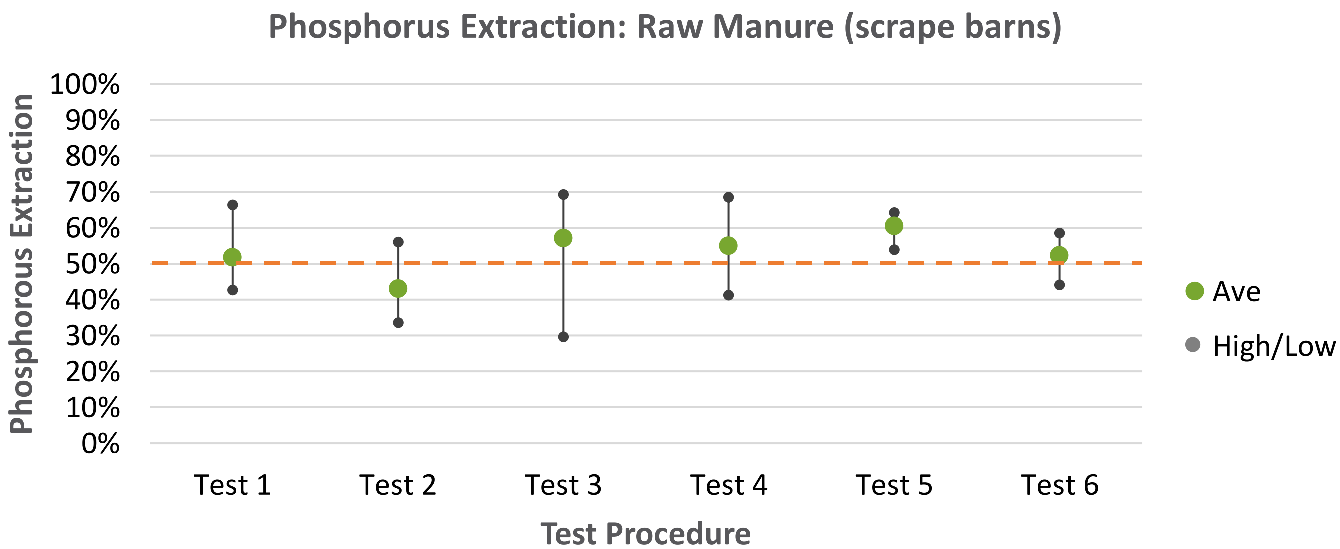
The primary purpose of this study was to assess the suitability and feasibility of using a centrifuge to enable B.C. dairy farmers to reduce excess soil phosphorus levels by extracting phosphorus from their dairy manure and exporting it off the farm. As such, and because it is assumed all centrate is applied to fields on the farm and all cake is exported off the farm, nutrient extraction efficiency (R) was calculated as the percentage of total ingoing manure nutrients (In) not captured in the centrate (Ce), as follows:

$$R = \left(\frac{In - Ce}{In}\right) \text{ x } 100$$

5.1 Phosphorus

Graph 1 shows average phosphorus extraction using raw manure from all farms with scrape collected manure. At different spin speeds (50%, 75% and 100%) phosphorus extraction was highest when feed rate was lowest (10 gpm as opposed to 20 gpm). A possible reason for this is that at the lower feed rate manure stayed inside the centrifuge for longer, allowing more time for centrifugal force to separate the centrate and cake. Average phosphorus extraction across all six farms ranged from as high as 60% (Test 5) to as low as 43% (Test 2). Highest phosphorus extraction achieved on any one farm was 69% (Test 3 and 4), and lowest phosphorus extraction achieved was 30% (Test 3).

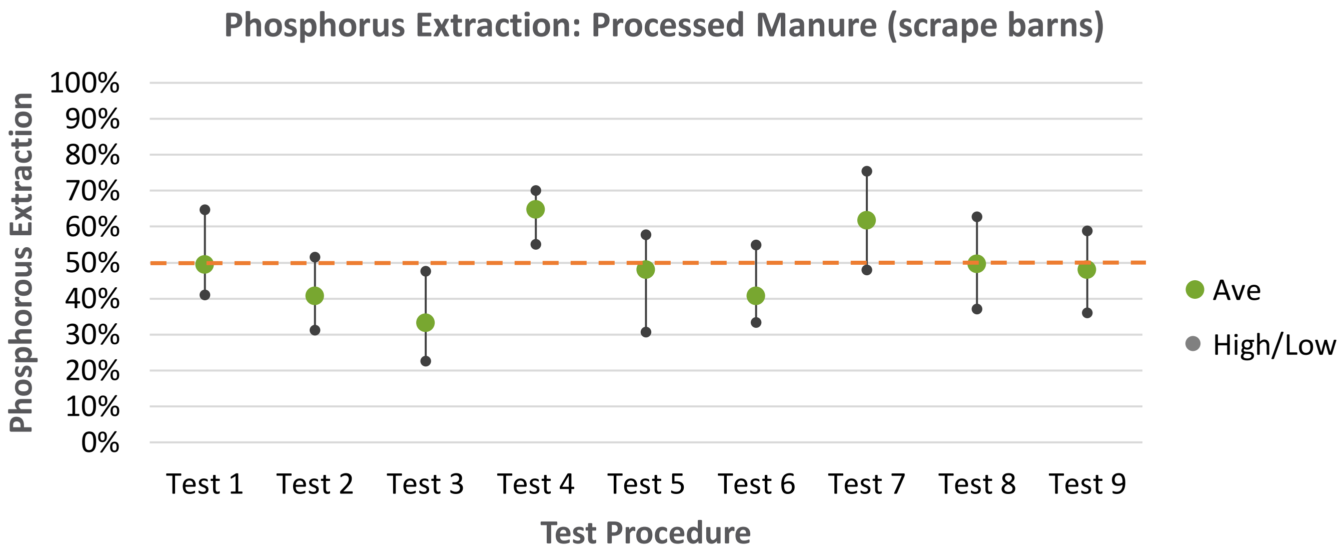
Graph 1: Phosphorus Extraction from Raw Manure (scrape barns)



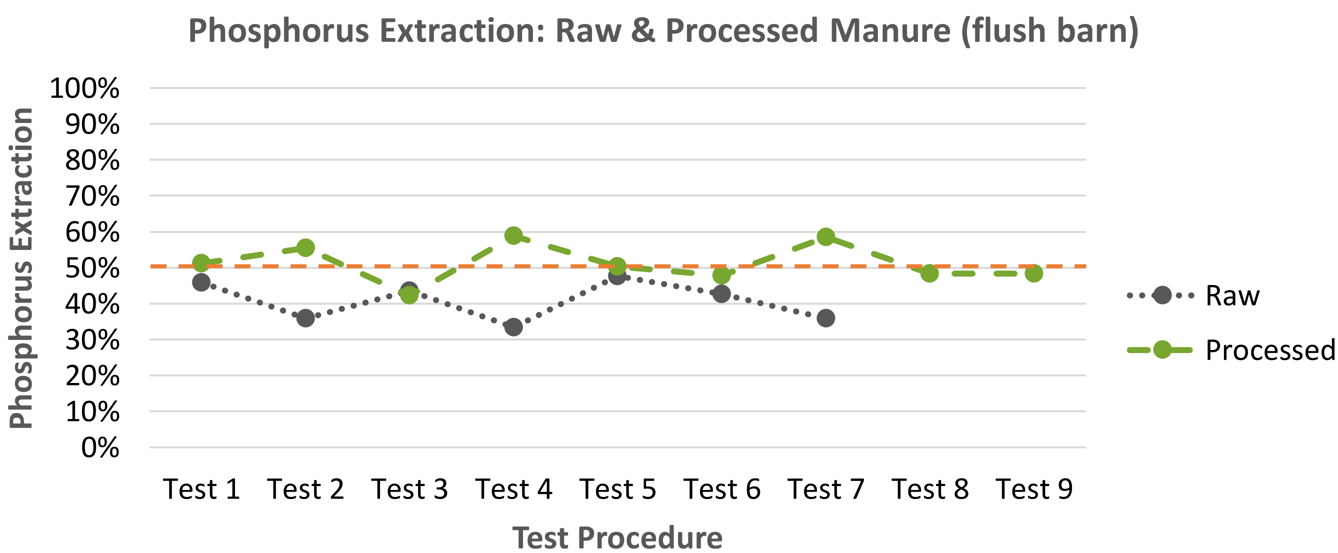
Graph 2 shows average phosphorus extraction using processed manure from all farms with scrape collected manure. At different spin speeds (50%, 75% and 100%) phosphorus extraction was highest when feed rate was lowest (10 gpm as opposed to 20 gpm or 25 gpm). Average phosphorus extraction across all six farms ranged from as high as 65% (Test 4) to as low as 33% (Test 3). Highest phosphorus extraction achieved on any one farm was 75% (Test 7), and lowest phosphorus extraction achieved was 23% (Test 3).

Graph 3 shows phosphorus extraction using raw and processed manure from flush collected manure. At different spin speeds (50%, 75% and 100%) phosphorus extraction was typically highest when feed rate was lowest (10 gpm as opposed to 20 gpm or 25 gpm). For raw manure, phosphorus extraction ranged from as high as 48% (Test 5) to as low as 33% (Test 4). For processed manure, phosphorus extraction ranged from as high as 59% (Test 4) to as low as 42% (Test 3).

Graph 2: Phosphorus Extraction from Processed Manure (scrape barns)



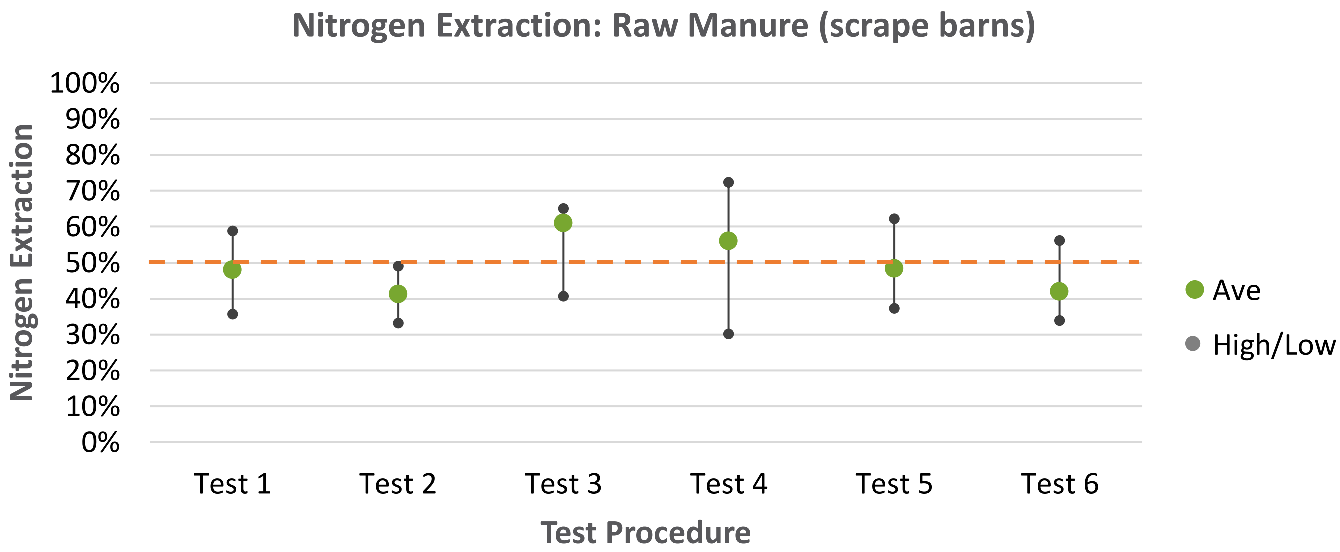
Graph 3: Phosphorus Extraction from Raw & Processed Manure (flush barn)



5.2 Nitrogen

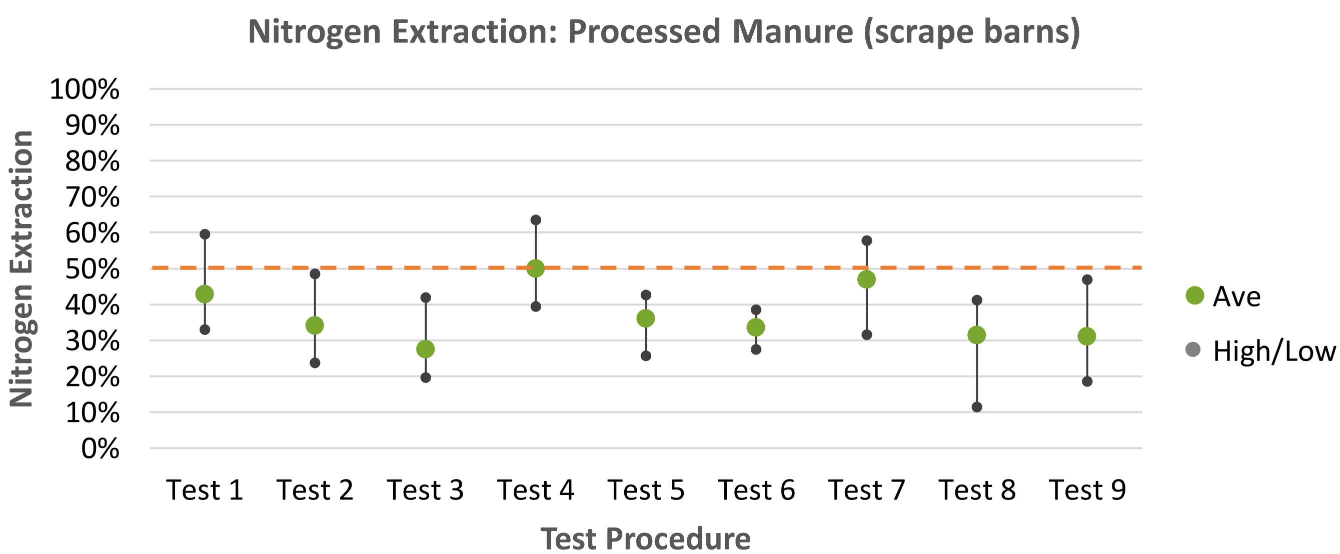
Graph 4 shows average nitrogen extraction using raw manure from all farms with scrape collected manure. At different spin speeds (50%, 75% and 100%) nitrogen extraction was highest when feed rate was lowest (10 gpm as opposed to 20 gpm). Average nitrogen extraction across all six farms ranged from as high as 61% (Test 3) to as low as 41% (Test 2). Highest nitrogen extraction achieved on any one farm was 72% (Test 4), and lowest nitrogen extraction achieved was 30% (Test 4).

Graph 4: Nitrogen Extraction from Raw Manure (scrape barns)



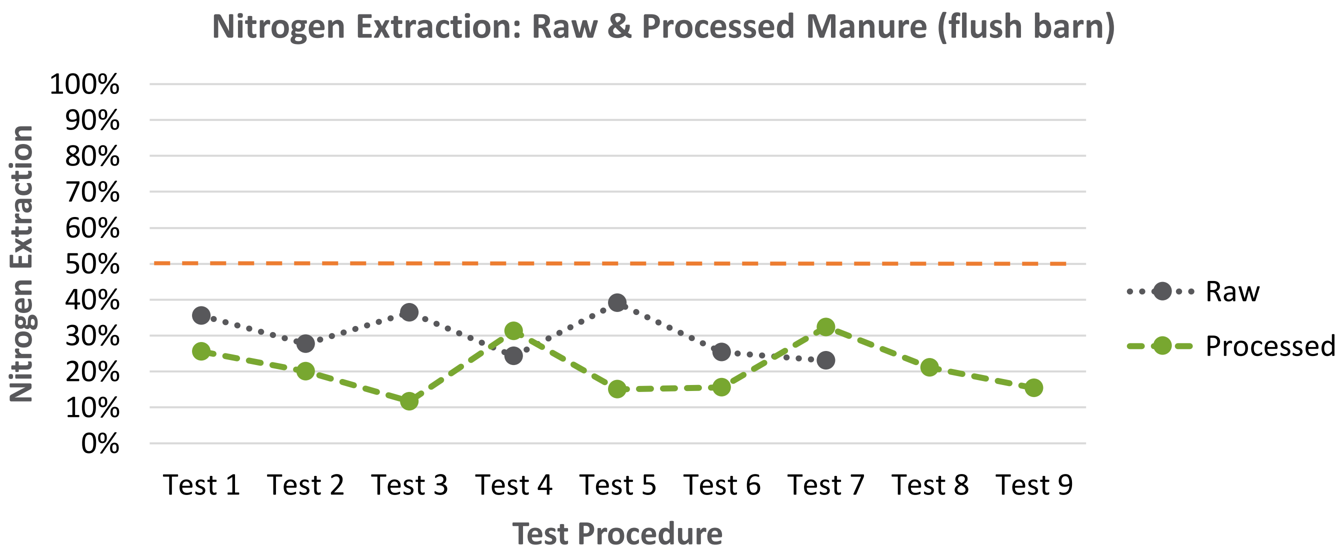
Graph 5 shows average nitrogen extraction using processed manure from all farms with scrape collected manure. At different spin speeds (50%, 75% and 100%) nitrogen extraction was highest when feed rate was lowest (10 gpm as opposed to 20 gpm or 25 gpm). Average nitrogen extraction across all six farms ranged from as high as 50% (Test 4) to as low as 27% (Test 3). Highest nitrogen extraction achieved on any one farm was 64% (Test 4), and lowest nitrogen extraction achieved was 11% (Test 8).

Graph 5: Nitrogen Extraction from Processed Manure (scrape barns)



Graph 6 shows nitrogen extraction using raw and processed manure from flush collected manure. At different spin speeds (50%, 75% and 100%) nitrogen extraction was highest when feed rate was lowest (10 gpm as opposed to 20 gpm or 25 gpm). For raw manure, nitrogen extraction ranged from as high as 39% (Test 5) to as low as 23% (Test 7). For processed manure, nitrogen extraction ranged from as high as 32% (Test 7) to as low as 12% (Test 3).

Graph 6: Nitrogen Extraction from Raw & Processed Manure (flush barn)



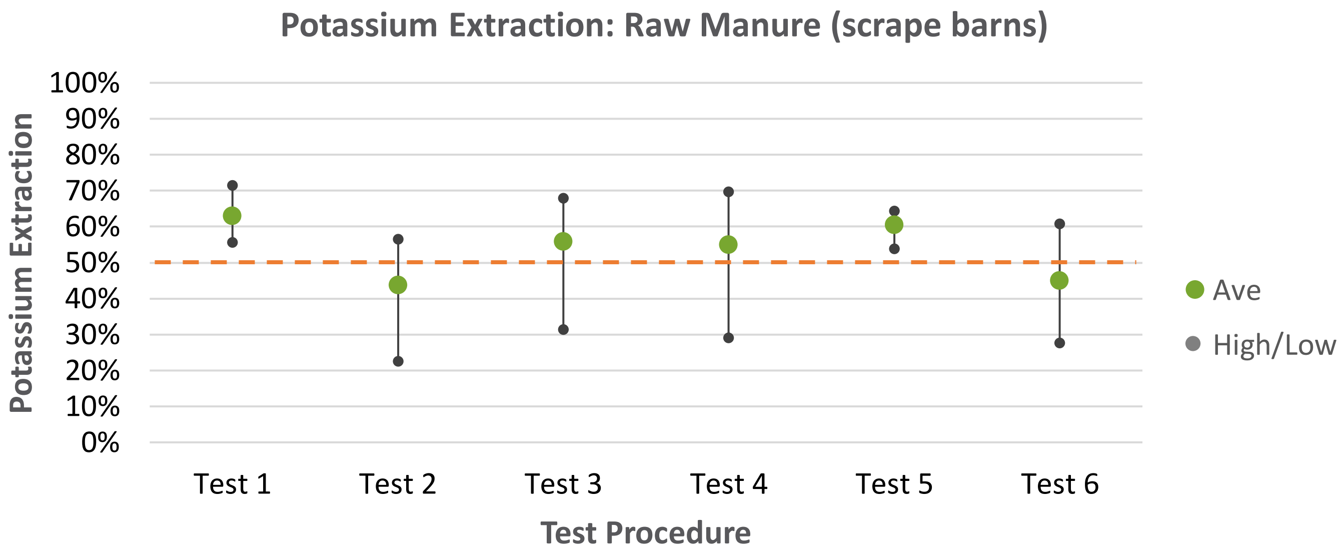
5.3 Potassium

Graph 7 shows average potassium extraction using raw manure from all farms with scrape collected manure. At different spin speeds (50%, 75% and 100%) potassium extraction was highest when feed rate was lowest (10 gpm as opposed to 20 gpm). Average potassium extraction across all six farms ranged from as high as 63% (Test 1) to as low as 44% (Test 2). Highest potassium extraction achieved on any one farm was 71% (Test 1), and lowest potassium extraction achieved was 23% (Test 2).

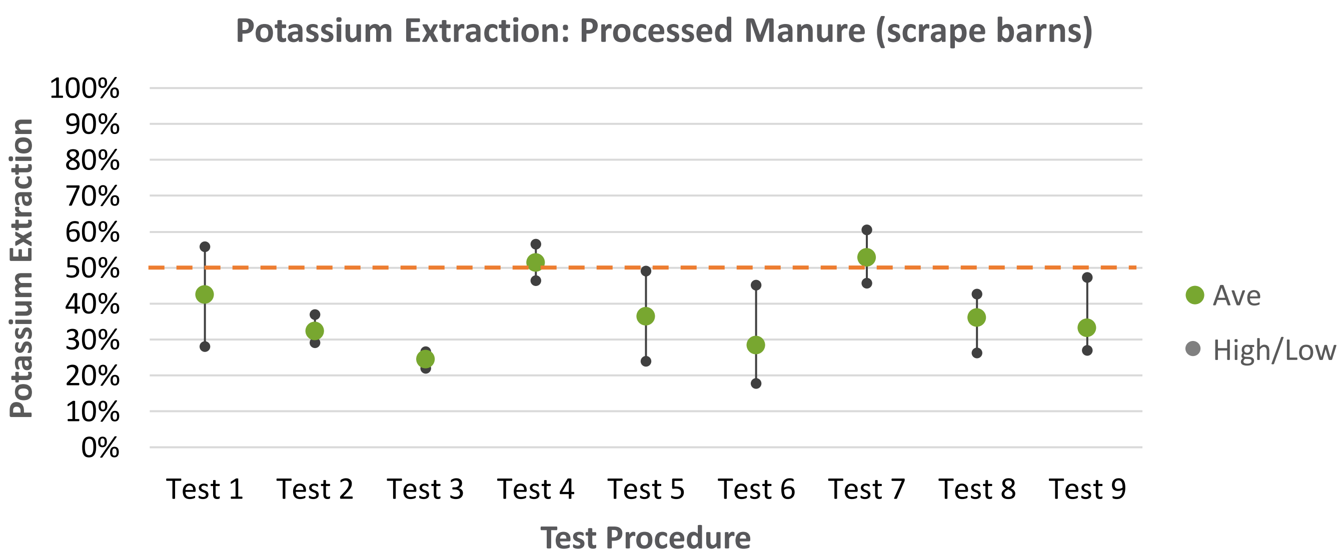
Graph 8 shows average potassium extraction using processed manure from all farms with scrape collected manure. At different spin speeds (50%, 75% and 100%) potassium extraction was highest when feed rate was lowest (10 gpm as opposed to 20 gpm or 25 gpm). Average potassium extraction across all six farms ranged from as high as 53% (Test 7) to as low as 25% (Test 3). Highest potassium extraction achieved on any one farm was 61% (Test 7), and lowest potassium extraction achieved was 18% (Test 6).

Graph 9 shows potassium extraction using raw and processed manure from flush collected manure. At different spin speeds (50%, 75% and 100%) potassium extraction was typically highest when feed rate was lowest (10 gpm as opposed to 20 gpm or 25 gpm). For raw manure, potassium extraction ranged from as high as 38% (Test 1) to as low as 16% (Test 4). For processed manure, potassium extraction ranged from as high as 47% (Test 7) to as low as 27% (Test 9).

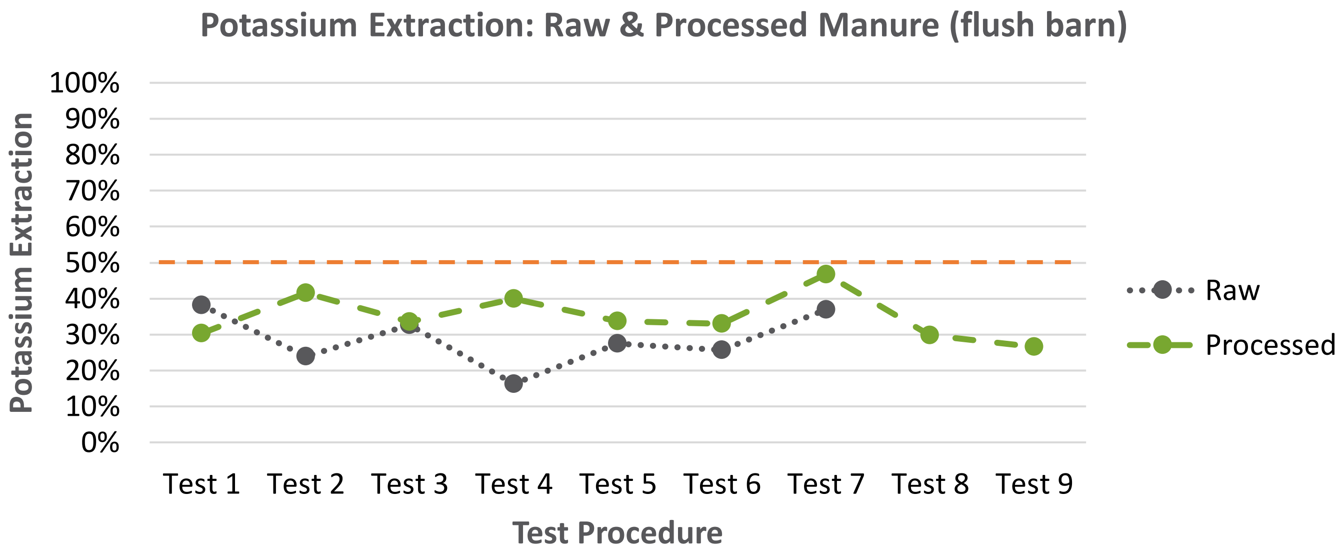
Graph 7: Potassium Extraction from Raw Manure (scrape barns)



Graph 8: Potassium Extraction from Processed Manure (scrape barns)



Graph 9: Potassium Extraction from Raw & Processed Manure (flush barn)



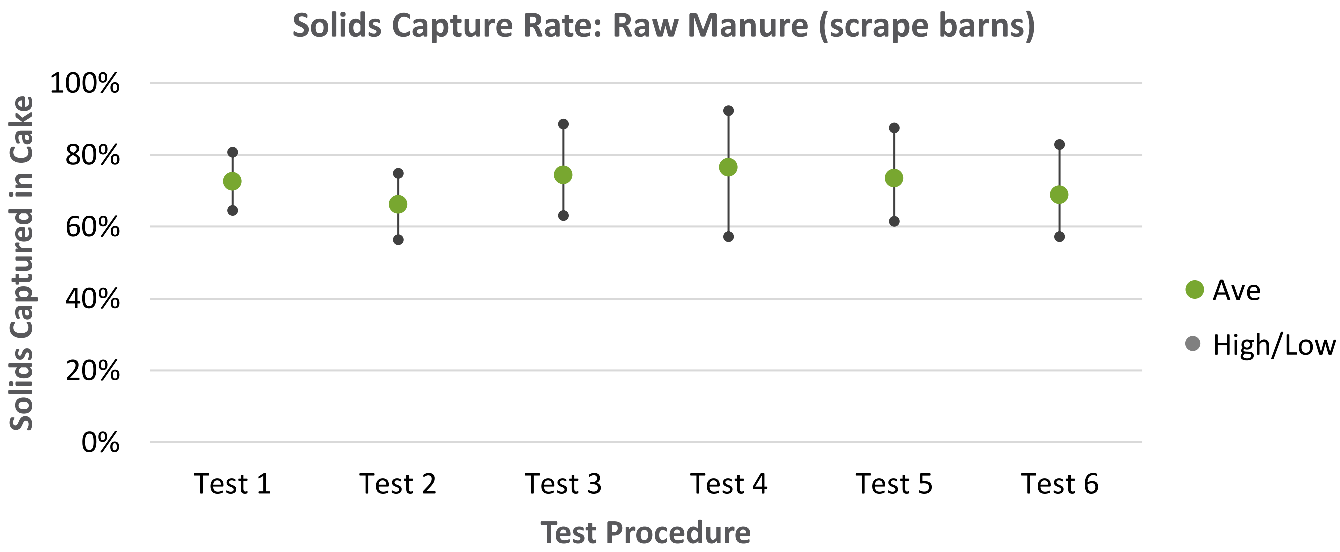
5.4 Solids Capture

Graph 10 shows average solids capture using raw manure from all farms with scrape collected manure. At different spin speeds (50%, 75% and 100%) solids capture was typically highest when feed rate was lowest (10 gpm as opposed to 20 gpm). Average solids capture across all six farms ranged from as high as 76% (Test 4) to as low as 66% (Test 2). Highest overall solids capture achieved on any one farm was 92% (Test 4), and lowest overall solids capture achieved was 56% (Test 2).

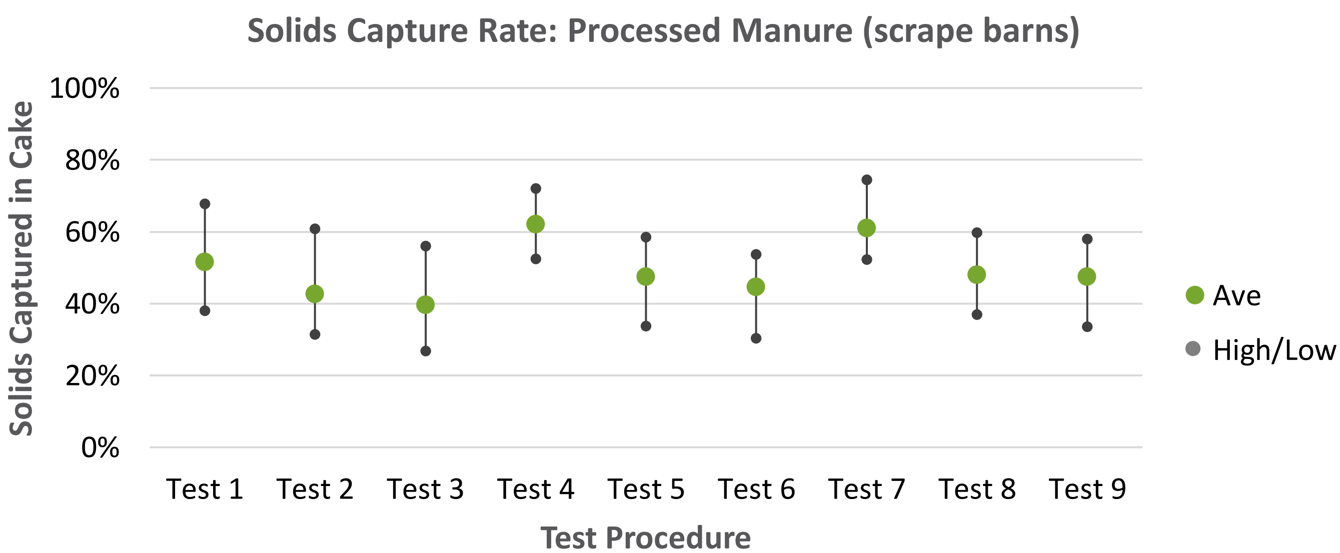
Graph 11 shows average solids capture using processed manure from all farms with scrape collected manure. At different spin speeds (50%, 75% and 100%) solids capture was highest when feed rate was lowest (10 gpm as opposed to 20 gpm or 25 gpm). Average solids capture across all six farms ranged from as high as 62% (Test 4) to as low as 40% (Test 3). Highest overall solids capture achieved on any one farm was 74% (Test 7), and lowest overall solids capture achieved was 27% (Test 3).

Graph 12 shows solids capture using raw and processed manure from flush collected manure. At different spin speeds (50%, 75% and 100%) solids capture was highest when feed rate was lowest (10 gpm as opposed to 20 gpm or 25 gpm). For raw manure, solids capture ranged from as high as 63% (Test 5) to as low as 51% (Test 7). For processed manure, solids capture ranged from as high as 55% (Tests 4 and 7) to as low as 42% (Tests 3 and 6).

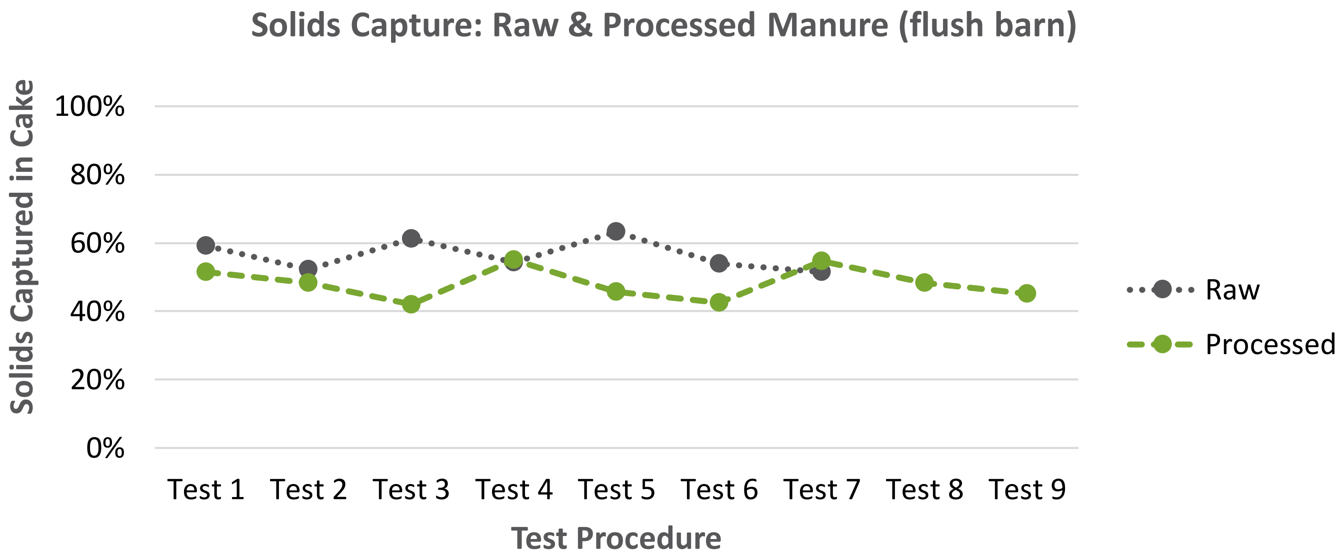
Graph 10: Solids Capture from Raw Manure (scrape barn)



Graph 11: Solids Capture from Processed Manure (scrape barn)



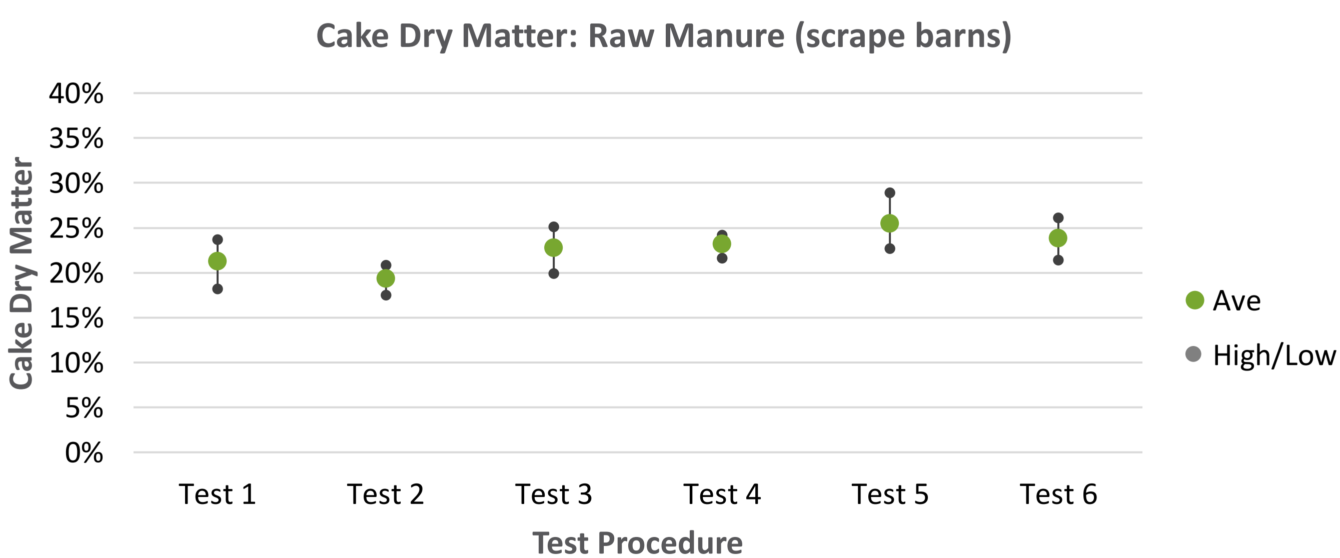
Graph 12: Solids Capture from Raw & Processed Manure (flush barn)



5.5 Dry Matter Content

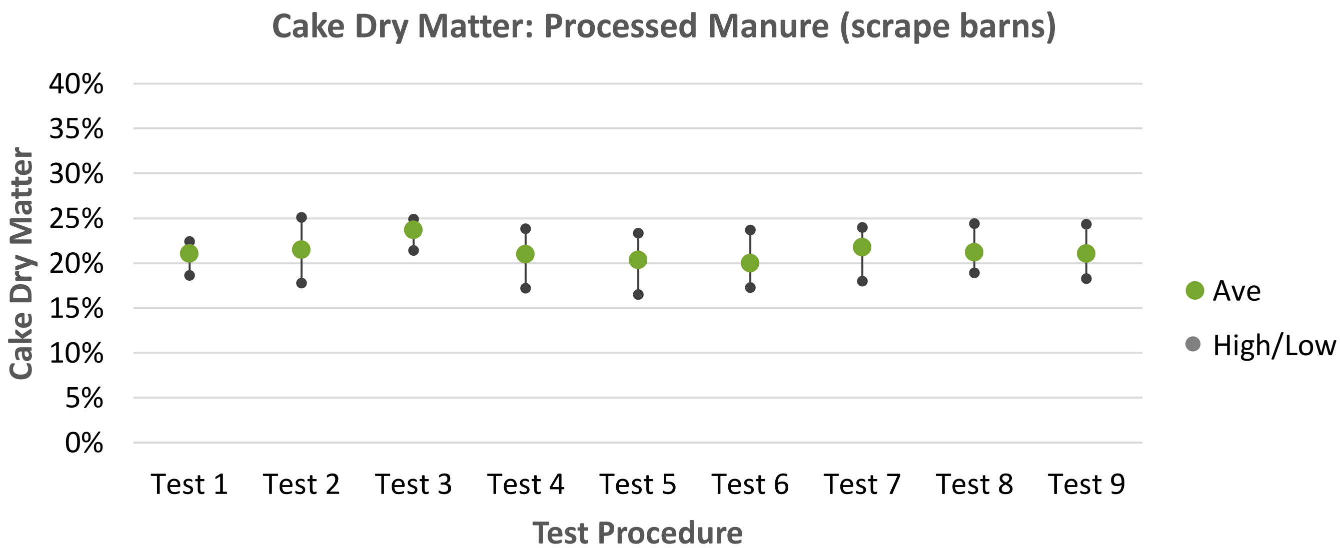
Graph 13 shows average cake dry matter using raw manure from all farms with scrape collected manure. At different spin speeds (50%, 75% and 100%) dry matter was typically highest when feed rate was lowest (10 gpm as opposed to 20 gpm). Average cake dry matter across all six farms ranged from as high as 25% (Test 5) to as low as 19% (Test 2). Highest overall dry matter achieved on any one farm was 29% (Test 5), and lowest overall dry matter achieved was 18% (Tests 1 and 2). Average centrate dry matter across all six farms ranged from 2 - 3%, while highest and lowest overall centrate dry matter achieved on any one farm were 4% and 1% respectively.

Graph 13: Cake Dry Matter from Raw Manure (scrape barn)



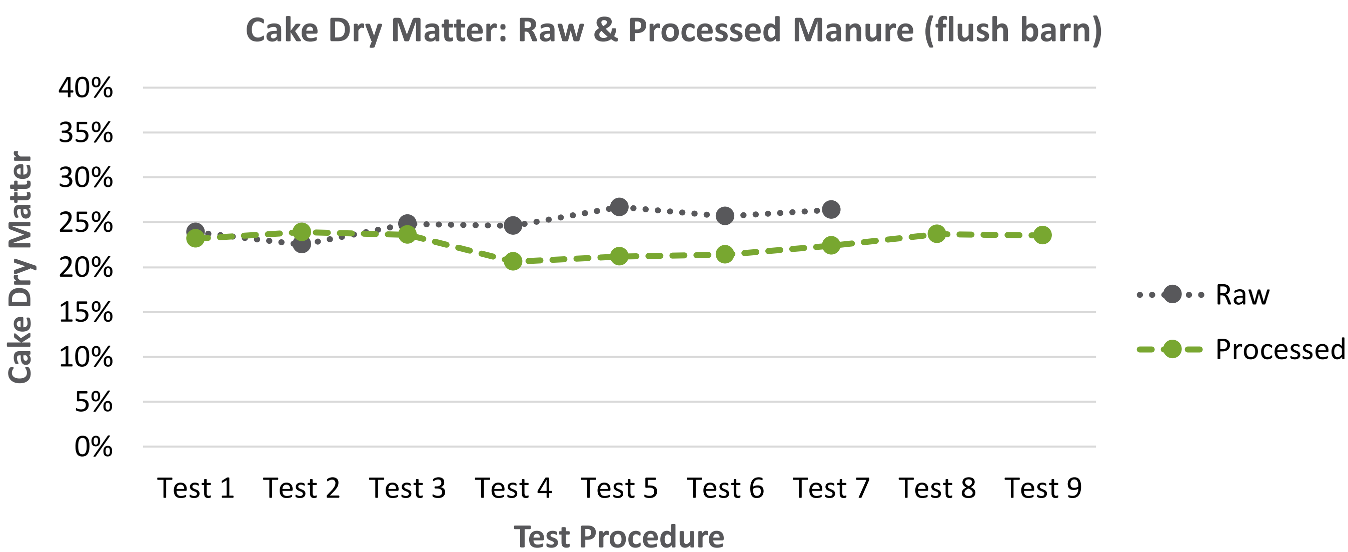
Graph 14 shows average cake dry matter using processed manure from all farms with scrape collected manure. At different spin speeds (50%, 75% and 100%) dry matter was typically highest when feed rate was lowest (10 gpm as opposed to 20 gpm or 25 gpm). Average cake dry matter across all six farms ranged from as high as 24% (Test 3) to as low as 20% (Tests 5 and 6). Highest overall dry matter achieved on any one farm was 25% (Tests 2 and 3), and lowest overall dry matter achieved was 17% (Tests 4, 5 and 6). Average centrate dry matter across all six farms was 2%, while highest and lowest overall centrate dry matter achieved on any one farm were 3% and 1% respectively.

Graph 14: Cake Dry Matter from Processed Manure (scrape barn)



Graph 15 shows cake dry matter using raw and processed manure from flush collected manure. At different spin speeds (50%, 75% and 100%) dry matter was highest (except raw manure Test 7 and processed manure Tests 2, 3, 8 and 9) when feed rate was lowest (10 gpm as opposed to 20 gpm or 25 gpm). For raw manure, cake dry matter ranged from as high as 27% (Test 5) to as low as 23% (Test 2). For processed manure, cake dry matter ranged from as high as 24% (Tests 2, 3, 8 and 9) to as low as 21% (Tests 4, 5 and 6). Centrate dry matter for raw and processed manure was 2%.

Graph 15: Cake Dry Matter from Raw & Processed Manure (flush barn)



5.6 Centrate & Cake Composition

Table 2 and 3 show average centrate and cake composition from scrape collected manure. Table 4 shows lowest and highest cake composition from flush collected manure. This information can be used to determine potential centrate application rates, and to show the nutrient value of cake.

Table 2: Average Centrate and Cake Composition from Raw Manure (scrape barn)

Test	Product	Dry matter	Total Nitrogen	Ammonia	Phosphorus	Potassium
1	Centrate	2.2%	0.19%	923 ppm	0.04%	0.11%
2		2.7%	0.22%	650 ppm	0.04%	0.16%
3		2.3%	0.18%	853 ppm	0.03%	0.17%
4		2.0%	0.17%	836 ppm	0.03%	0.16%
5		2.4%	0.19%	930 ppm	0.03%	0.19%
6		2.8%	0.21%	1,041 ppm	0.04%	0.23%
Average		**2.4%**	**0.194%**	**872 ppm**	**0.036%**	**0.168%**
1	Cake	21.2%	0.48%	930 ppm	0.14%	0.20%
2		19.4%	0.45%	1,192 ppm	0.10%	0.19%
3		22.8%	0.49%	948 ppm	0.15%	0.19%
4		23.2%	0.47%	577 ppm	0.14%	0.18%
5		25.5%	0.56%	787 ppm	0.17%	0.22%
6		23.8%	0.56%	1,538 ppm	0.15%	0.21%
Average		**22.6%**	**0.500%**	**995 ppm**	**0.141%**	**0.198%**

Table 3: Average Centrate and Cake Composition from Processed Manure (scrape barn)

Test	Product	Dry matter	Total Nitrogen	Ammonia	Phosphorus	Potassium
1	Centrate	1.8%	0.15%	717 ppm	0.03%	0.12%
2		2.1%	0.17%	844 ppm	0.03%	0.14%
3		2.2%	0.19%	923 ppm	0.04%	0.16%
4		1.6%	0.14%	677 ppm	0.02%	0.14%
5		2.2%	0.17%	809 ppm	0.03%	0.18%
6		2.3%	0.18%	849 ppm	0.04%	0.21%
7		1.7%	0.14%	734 ppm	0.02%	0.14%
8		2.2%	0.18%	901 ppm	0.03%	0.18%
9		2.2%	0.18%	916 ppm	0.03%	0.18%
Average		**2.0%**	**0.165%**	**819 ppm**	**0.032%**	**0.159%**
1	Cake	21.0%	0.56%	1,247 ppm	0.22%	0.16%
2		21.5%	0.56%	1,220 ppm	0.19%	0.18%
3		23.7%	0.58%	1,299 ppm	0.21%	0.17%
4		21.0%	0.54%	1,405 ppm	0.31%	0.24%
5		20.3%	0.52%	1,249 ppm	0.31%	0.23%
6		20.0%	0.49%	1,267 ppm	0.28%	0.23%
7		21.7%	0.55%	1,302 ppm	0.38%	0.24%
8		21.2%	0.55%	1,566 ppm	0.36%	0.25%
9		21.1%	0.52%	1,284 ppm	0.38%	0.24%
Average		**21.3%**	**0.540%**	**1,315 ppm**	**0.293%**	**0.216%**

Table 4: Lowest/Highest Centrate & Cake Composition from Raw & Processed Manure (flush barn)

Test		Test	Product	Dry matter	Total Nitrogen	Ammonia	Phosphorus	Potassium
1	Raw	Low	Centrate	1.9%	0.174%	911 ppm	0.024%	0.098%
4		High		2.1%	0.202%	1,045 ppm	0.029%	0.131%
2		Low	Cake	22.5%	0.452%	288 ppm	0.092%	0.162%
7		High		26.4%	0.712%	943 ppm	0.168%	0.257%
7	Proc-essed	Low	Centrate	1.6%	0.152%	821 ppm	0.018%	0.084%
3		High		2.0%	0.194%	1,086 ppm	0.025%	0.102%
3		Low	Cake	23.6%	0.513%	1,904 ppm	0.169%	0.074%
9		High		23.5%	0.677%	1,640 ppm	0.236%	0.089%

5.7 Discussion

Unsurprisingly, highest average phosphorus and nitrogen extraction, and highest average solids capture occurred when centrifuge feed rate was lowest (10 gpm) and spin speed highest (75% or 100%). Highest average potassium extraction also occurred when feed rate was lowest (10 gpm), although spin speed had little impact. Average cake dry matter from raw manure was highest when centrifuge feed rate was lowest (10 gpm) and spin speed highest (100%). For processed manure there was no pattern between cake dry matter, feed rate and spin speed. Average centrate dry matter for all farms was 2% - 3%.

Nutrient extract, solids capture and cake dry matter varied between farms. For example, phosphorus extraction at the same centrifuge feed rate and spin speed from scrape collected raw and processed manure varied by up to 40% and 27% respectively. One reason for this variation could be differences in manure particle size distribution. Manure particle size distribution is affected by multiple variables, including cow diet and age, manure collection method and decomposition. For example, manure stored for longer periods of time will likely experience greater decomposition and therefore have more fine particles than manure recently removed from the barn. Centrifuge performance generally improves when manure has less fine particles, as these particles are more difficult to separate.

Average nutrient extract, solids capture and cake dry matter also varied between raw and processed manure. For example, average phosphorus extraction using scrape collected raw manure was 43% - 60%, while average phosphorus extraction using scrape collected processed manure was 33% - 65%. Average solids capture and cake dry matter using scrape collected raw manure was 66% - 76% and 18% - 29% respectively, while average solids capture and cake dry matter using scrape collected processed manure was lower at 40% - 62% and 17% - 25% respectively.

One reason for this variation is that processed manure has been through solid-liquid separation to extract large fibre. Extracting large fibre removes some phosphorus (resulting in lower extraction), and causes ammonia volatilization (resulting in loss of nitrogen). Furthermore, extracting large fibre reduces manure dry matter (resulting in less solids capture), and removes drier fibre (resulting in lower dry matter cake). Extracting large fibre also results in higher cake bulk density (cake from raw and processed manure was typically 500 - 600kg/m^3 and 750 - 850kg/m^3 respectively), and a lower cake volume (cake from raw manure was typically twice the volume than from processed manure). The physical differences between cake from raw and processed manure can easily be seen in Figure 5.

Based on these results and regardless if using raw or processed manure, running a centrifuge at a low feed rate (i.e., 10 gpm) and high spin speed (i.e., 75% or 100%), should enable B.C. dairy farmers with scrape collected manure to extract 60% of the phosphorus from their dairy manure. At the same time, approximately 40% - 60% of the nitrogen and potassium may also be extracted. Cake and centrate should have a dry matter content of approximately 22% - 25% and 2% - 3% respectively. If the centrifuge were run at a high feed rate and/or lower spin speed, nutrient extraction should be lower.

For B.C. dairy farms with flush collected manure and regardless if using raw or processed manure, running a centrifuge at a low feed rate (i.e., 10 gpm) and high spin speed (i.e., 75% or 100%) should enable them to extract up to 50% of the phosphorus from their dairy manure. At the same time, approximately 25% - 40% of the nitrogen and potassium may also be extracted. Cake and centrate should have a dry matter content of approximately 24% - 27% and 2% respectively. If the centrifuge were run at a high feed rate and/or lower spin speed, nutrient extraction should be lower.

Figure 5: Photo of Cake from Raw Manure (left) and Processed Manure (right)

6. Example Nutrient Management Plan

Understanding how centrifuge nutrient extraction could benefit a B.C. dairy farm is difficult to determine unless information is known about the farm's current situation. The following example, using a fictitious B.C. dairy farm (Farm XYZ), provides a good example of how a centrifuge could enable B.C. dairy farms to meet a Nutrient Management Plan (NMP)[5].

Farm XYZ, located in the Fraser Valley, is a 360 cow (300 milk cow and 60 dry cow) operation with 290 acres (117 hectares) of productive farmland (owned and rented). Farm XYZ grows perennial forage grass and forage corn for feeding the herd, which is housed year round. Farm XYZ doesn't have solid-liquid separation, and manure storage consists of in-ground uncovered concrete storage. Soil samples taken from Farm XYZ's fields in the spring are summarised in Table 5.

Table 5: Farm XYZ's Soil Analysis Summary

Field	Soil Test Phosphorus	Available Soil Nitrogen	Soil Test Potassium
Field 1: Grass	Optimum (73 ppm)	Deficient (3 ppm)	High (306 ppm)
Field 2: Corn	Excess (200 ppm)	Deficient (4 ppm)	Excess (543 ppm)
Field 3: Grass	Excess (160 ppm)	Deficient (8 ppm)	Excess (428 ppm)
Field 4: Grass	Optimum (70 ppm)	Deficient (5 ppm)	Optimum+ (186 ppm)
Field 5: Grass	Excess (140 ppm)	Deficient (6 ppm)	High (256 ppm)

[5] All seven dairy farmers that participated in the study received a NMP specific to their farm.

Based on the soil analyses in Table 5, the following observations can be made:

- Phosphorus levels are currently optimum to excess (73 - 200 ppm) in all fields;
- Nitrogen levels in all fields are deficient. This is expected in early spring because crops continue to grow into the late fall, using up all nitrogen applied according to recommended nutrient application rates. If any residual nitrogen exists after fall growth, this leaches through the soil column because of heavy precipitation during late fall and early winter; and
- Potassium levels are optimum+ to excess (186 - 543 ppm) in all fields.

Manure nutrient composition used for the NMP (Table 6) is based upon manure samples taken from Farm XYZ's in-ground uncovered concrete storage, and assuming centrifuge nutrient extraction of approximately 60% phosphorus, and 50% nitrogen and potassium.

Table 6: Farm XYZ's Manure Nutrients

Manure	Cake	Centrate
Nitrogen: 0.25% (5.0 lb/ton)	Nitrogen: 0.39% (7.8 lb/ton)	Nitrogen: 0.15% (3.0 lb/ton)
Phosphorus: 0.05% (1.0 lb/ton)	Phosphorus: 0.15% (3.0 lb/ton)	Phosphorus: 0.02% (0.4 lb/ton)
Potassium: 0.21% (4.2 lb/ton)	Potassium: 0.75% (15.0 lb/ton)	Potassium: 0.13% (3.6 lb/ton)

Farm XYZ currently generates approximately 16,200 tonnes/year of manure and waste feed, and collects approximately 700 tonnes/year of rainwater (for a total of 16,900 tonnes/year). When 16,900 tonnes/year of liquid manure is spread on the farm's fields with 390 tonnes/year of solid manure from calf pens and dry pack, Farm XYZ has surplus phosphate (P_2O_5) and potash (K_2O) in every field. The farm needs to purchase approximately 25,000 lb/year of nitrogen (Table 7).

Table 7: Farm XYZ's Baseline Nutrient Balance

Field	Crop	Nutrient Balance (crop removal – total nutrients)*		
		P_2O_5 (lb/acre)	Nitrogen (lb/acre)	K_2O (lb/acre)
Field 1	Grass	+47	-113	+40
Field 2	Corn	+60	-31	+122
Field 3	Grass	+56	-79	+64
Field 4	Grass	+58	-105	+72
Field 5	Grass	+50	-61	+61

*Note: *A plus sign indicates excess nutrients, while a minus sign indicates deficient nutrients.*

If Farm XYZ were to install a centrifuge to extract 60% phosphorus, and 50% nitrogen and potassium from its manure, if only the centrate (approximately 14,200 tonnes/year) and solid manure from calf pens and dry pack (390 tonnes/year) were spread on the farm's fields, and if all cake were exported off the farm (approximately 2,700 tonnes/year), every field would be deficient in phosphate and potash. The farm would need to purchase approximately 44,000 lb/year of nitrogen (Table 8).

Table 8: Farm XYZ's Nutrient Balance with Centrifuge

Field	Crop	Nutrient Balance (crop removal – total nutrients)*		
		P_2O_5 (lb/acre)	Nitrogen (lb/acre)	K_2O (lb/acre)
Field 1	Grass	-47	-177	-101
Field 2	Corn	-12	-94	-23
Field 3	Grass	-38	-143	-77
Field 4	Grass	-35	-169	-68
Field 5	Grass	-35	-123	-76

*Note: *A plus sign indicates excess nutrients, while a minus sign indicates deficient nutrients.*

Processing Farm XYZ's manure in a centrifuge results in every field being deficient in phosphate, nitrogen, and potash. One option for reducing this deficiency is to run the centrifuge at a lower spin speed and/or high feed rate. For example, if only 30% phosphorus, and 25% nitrogen and potassium were extracted from Farm XYZ's dairy manure, fields would be much more balanced for phosphate and potash. Farm XYZ would still need to buy nitrogen.

Another option is to increase herd size. If Farm XYZ increased its herd size from 300 milk and 60 dry cows (plus heifers), to 500 milk and 100 dry cows (plus heifers), it would produce approximately 25,700 tonnes/year of manure. If this manure were put through a centrifuge to extract 60% phosphorus, and 50% nitrogen and potassium, it would produce approximately 21,600 tonnes/year of centrate and 3,900 tonnes/year of cake. If all centrate and solid manure from calf pens and dry pack (approximately 600 tonnes/year) were spread on Farm XYZ's fields, and if all cake were exported off the farm, every field would be balanced for phosphate and slightly surplus in potash.[6] Farm XYZ would need to purchase approximately 34,000 lb/year of nitrogen (Table 9).

It should be noted that the above scenario only works if all cake (approximately 3,900 tonnes/year or 6,500m^3/year) is exported off the farm. While cake has a higher nutrient concentration than dairy manure, there is currently no defined B.C. market in which to sell this cake, and there are no local examples of long-term agreements in which cake is removed from a farm for free. Furthermore, some areas of BC, such as the Lower Mainland, already have large volumes of organic soil amendments available, such as poultry litter. It is therefore important that before any B.C. dairy farmer chooses to install a centrifuge, a suitable, long-term plan for getting cake off the farm is developed.

One option could be to dry cake through composting or with a mechanical dryer. However, while this will add value to the cake, it will also add cost. Another option could be to find local growers, such as

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[6] Of the seven dairy farms participating in this study, it was found that every farmer could increase their herd size by at least 15% and still meet the requirements of a nutrient management plan, even without purchasing or renting additional land.

potato or alfalfa farmers, who will sign long-term agreements to collect the cake for free. Whatever decision is taken, it must be carefully considered and planned out beforehand; otherwise B.C. dairy farmers may pay to have cake taken away.

Table 9: Farm XYZ's Nutrient Balance with Centrifuge + More Cows

Field	Crop	Nutrient Balance (crop removal – total nutrients)*		
		P_2O_5 (lb/acre)	Nitrogen (lb/acre)	K_2O (lb/acre)
Field 1	Grass	-12	-137	+11
Field 2	Corn	-2	-81	+8
Field 3	Grass	-4	-103	+35
Field 4	Grass	-5	-135	+28
Field 5	Grass	-8	-85	+18

*Note: *A plus sign indicates excess nutrients, while a minus sign indicates deficient nutrients.*

7. Centrifuge Ownership

7.1 The Ownership Options

While considered small by industry standards, the smallest centrifuges are too large for most B.C. dairy farms. Typically, the smallest centrifuges can process up to 25 gpm of manure. Running 12 hours/day, 5 days/week, a 25 gpm centrifuge can process manure from a 320 milk cow (and associated livestock) farm. Running 24 hours/day, seven days a week, a 25 gpm centrifuge could process manure from a 900 milk cow (and associated livestock) farm. The average B.C. dairy farm has 150 - 200 milk cows.

In addition to being larger than most B.C. dairy farms require, centrifuge purchase cost per tonne of manure throughput decreases dramatically with size. For example, centrifuges capable of processing 25 gpm of manure are approximately only half the price of centrifuges capable of processing six to eight times more manure (100 gpm - 150 gpm). Due to centrifuge size and cost, there are three ownership options B.C. dairy farmers should consider; sole ownership (including leasing), joint ownership, and contracted services (custom hire). These ownership options, including their advantages and disadvantages, are discussed below.

7.2 Sole Ownership

Sole ownership, purchasing or leasing, is the most common and simplest form of ownership, and gives greatest amount of control as only one farmer has sole right of use. Perhaps the greatest advantage of sole ownership is that the farmer has complete control over when manure is processed, and as such the manure can be processed as it is removed from the barn. This enables centrate to be stored in the farm's current manure storage as it is no longer required for manure. At a solids capture rate of 60% - 80%, volume of centrate will be approximately 10% - 15% less than the volume of manure removed from the barns, increasing existing manure storage capacity by approximately 10% - 15%.

Additional storage will be required for cake. Size of storage depends upon the volume and dry matter of the manure, cake bulk density, and length of time it will be stored on the farm. For example, if a farm processes 20,000 tonnes/year of manure in a centrifuge and captures 3,000 tonnes/year of cake, if this cake has a bulk density of 600kg/m^3, and if this cake is removed from the farm at the end of every month, approximately 420m^3 (550 yards) of cake would require storage. Assuming a pile height of three meters, the storage area would need to be approximately 140m^2 (1,500 $feet^2$).

7.3 Joint Ownership

Designed to be stationary but potentially mobile due to their small footprint, centrifuges can be jointly owned by two or more dairy farmers. Perhaps the greatest advantage of joint ownership is that multiple farmers in a relatively small area can benefit from the technology while spreading, and therefore reducing, costs. While purchase of a single piece of equipment for multi-farm use in B.C. is uncommon unless within a family, there are many successful examples of agricultural machinery joint ownership in Canada, such as combines. Centrifuges, because they are needed all year and not just at certain times (such as with combines during harvest), are an ideal technology to share.

Successful joint ownership requires a clearly written agreement, and ongoing good communication between participating farmers. This written agreement should include clear rules and legally binding contracts that spell out the rights and obligations of each participating farmer, as well as details about centrifuge use, insurance, maintenance and repairs, records, biosecurity, transportation, replacement, etc. Some key questions that must be answered when preparing a joint ownership agreement include:

- Which ownership structure will be used (i.e., sole ownership with leasing arrangements to the other farmers, equal joint ownership, or joint ownership based upon farm size)?
- Which ancillary equipment will be purchased with the centrifuge (i.e., will it have its own trailer, generator, pressure washer, dump tank, etc.)?
- Who will use the centrifuge on which days (i.e., will each farmer use the centrifuge one day per cycle, one week per cycle, one month per cycle, etc.)?
- How will the centrifuge be transported between farms (i.e., will it be towed using the farm's truck, by a truck purchased specifically for the centrifuge, or by a third party)?
- Who will be responsible for transporting the centrifuge (i.e., is it the farmer that used the centrifuge last, the farmer that will use it next, or a third party)?
- Will there be a maximum volume of manure that can be processed by each farmer (i.e., are farmers allowed to process as much manure as they like, or are they limited)?
- Will there be a maximum number of hours the centrifuge can be operate each day (i.e., are farmers allowed to operate the centrifuge as many hours a day as they like, or are they limited)?
- Can the centrifuge be loaned or rented to farmers not part of the ownership agreement (i.e., can a farmer lend the centrifuge to a neighbor or family member, or are only farmers named on the agreement allowed to use it)?
- How must the centrifuge be housed on each farm (i.e., can the centrifuge be housed outside, or

must it be housed under some type of cover)?

- What procedure will be followed to ensure the next farm is protected from biosecurity threats (i.e., what will farmers be responsible for to ensure they don't transport disease-causing organisms to other farms)?
- Who will be responsible for organizing insurance, and what insurance is needed (i.e., what is required to ensure full coverage and liability)?
- Who will be responsible for organizing on-going maintenance and necessary repairs (i.e., will this be the sole responsibility of one farmer, or will responsibility be rotated between farmers)?
- What schedule will be used to determine when maintenance work is required (i.e., will it be based on number of days, volume of manure processed, hours of operation, etc.)?
- What repairs can be done by the farmer, and what will require an independent third party (i.e., if something breaks, can a farmer make the repairs, or must it be fixed by a third party)?
- If a third party is required to make repairs, which company will be used (i.e., the company that supplied the centrifuge, a local company, someone else, or all of the above)?
- If the centrifuge requires unscheduled repairs, how will this impact the farmer's use of the centrifuge (i.e., will the farmer be allowed to use the centrifuge for additional days to compensate for the downtime, and if so, will there be a maximum number of days)?
- What procedure will be used for determining if the cause of repairs is due to careless operation or regular wear and tear, and what method will be used for dealing with breakdowns caused by misuse (i.e., if the centrifuge breaks down due to negligence, how will this be determined and dealt with)?
- What will happen if the centrifuge isn't available to the next farmer on the assigned days (i.e., if the centrifuge isn't delivered or able to be delivered to the next farm when scheduled, will the proceeding farmer be penalized in anyway)?
- What type of mechanism will be used to address disputes or grievances that may arise (i.e., will it be mediation, arbitration, litigation, etc.)?
- Will there be a centrifuge record book, and if so, which records will be kept (i.e., if there is a record book, will records be kept on volume of manure processed and hours of operation, date and time of breakdowns, date, time, and nature of repairs or maintenance performed)?
- What will be the initial term of the agreement, and can the agreement be extended at the end of this term (i.e., will it be a 5, 10 or 15 year agreement, and once the agreement expires can it be extended, or will a new agreement be required)?
- What will happen in the event of a retirement or untimely death (i.e., if a farmer retires or passes away, how will this unforeseen circumstance be dealt with)?
- If the agreement requires termination, how will the centrifuge's value be determined at the time of dissolution (i.e., if the joint ownership agreement is canceled, how will the value of the centrifuge, and therefore how much money each farmer will receive, be decided)?

Ownership structure must be agreed upon. There are three basic structures that should be considered. The first, and easiest to implement, is sole ownership with a leasing arrangement. Under sole ownership, one farmer owns a centrifuge and charges other farmers (stakeholders) for its use with contracted use guarantees. The second is joint ownership, where a centrifuge is owned on an equal basis by all participating farmers. If each farmer uses the centrifuge to process the same amount of manure, this arrangement works well. Repair costs, financing payments, income tax deductions, etc. are divided equally.

In reality, farmers have different volumes of manure. When one farmer uses a centrifuge to process more manure than other farmers, a third ownership structure might work best. This is joint ownership based upon farm size; each farmer owns a percentage of the centrifuge based on the amount of manure they process relative to the other farmers. For example, if Farm A has twice as much manure as Farm B, C, and D, Farmer A would own 40% of the centrifuge and pay 40% of maintenance, repair and other costs, while Farmers B, C and D would own 20% (and therefore pay 20% of the costs). This arrangement works if participating farmers use the centrifuge proportionally to their ownership share.

Another, more flexible option is for all farmers to contribute to a special account, paying an agreed upon rate multiplied by each gallon of manure they process. All non-energy and labour centrifuge related expenses, such as debt repayment, maintenance and repairs, etc. are paid from this account. At year end, any excess or deficit is carried over to the following year, or refunded in proportion to each farmer's actual use (Example A). Alternately, the farmers with the most manure could reimburse the other farmers for extra use. This reimbursement would be an agreed upon rate multiplied by each gallon of manure processed above the farmer's ownership share (Example B).

Whether sole ownership, joint ownership, joint ownership based upon farm size is used, the centrifuge will require some type of gauge to measure manure flow. This gauge must be calibrated and testing periodically to ensure accuracy.

Minimizing time and cost is also key to successful and economically advantageous joint ownership of a centrifuge. Because centrifuges are needed all year and not just at specific times, and because manure can be stored for several months, the length of time that centrifuges can be used by farmers participating in joint ownership can vary greatly. For example, if four dairy farmers agree to share a centrifuge, they may agree each farmer uses it one day in every four, one week in every four, or one month in every four.

Before a decision is made concerning the length of time that farmers use a centrifuge, three important factors must be considered. The first is time. Whenever a centrifuge is transported from farm to farm, it will require break-down, cleaning, transportation, and set-up. While the time to complete these steps will vary depending upon centrifuge size, if it is connected to a portable generator or tied into the farm's electrical service, and distance between farms, the more often a centrifuge is moved, the more time is required to do so. For this reason, generally speaking, the longer the sharing cycle (i.e., the more time the centrifuge is on a farm at a time) the better.

Example A

Farmer A, B, C, and D purchase a mobile centrifuge for $500,000, agreeing to pay $0.01 to a joint account for each gallon of manure processed:

- Farm A: 8 million gallons =	$80,000
- Farm B: 4.5 million gallons =	$45,000
- Farm C: 2.0 million gallons =	$20,000
- Farm D: 1.5 million gallons =	$15,000
	$160,000

Expenses paid from the joint account include:

- Debt repayment (plus interest) =	$90,000
- Maintenance and repairs =	$60,000
- Insurance =	$5,000
	$155,000

Excess funds carried over to next year, or refunded in proportion to each farm's actual use:

- Income =	$160,000
- Expenses =	$155,000
- Excess =	$5,000

Example B

Farmer A, B, C, and D purchase a mobile centrifuge for $500,000, paying 25% each. Centrifuge cost is $0.01/gallon of manure, and is used by each farm as follows:

- Farm A: 8 million gallons;
- Farm B: 4.5 million gallons;
- Farm C: 2.0 million gallons; and
- Farm D: 1.5 million gallons.

Each farmer has a 25% ownership share. 25% of total manure is 4 million gallons. Farmer A and B therefore pay Farmer C and D $0.01 for each extra gallon of manure they process above 4 million:

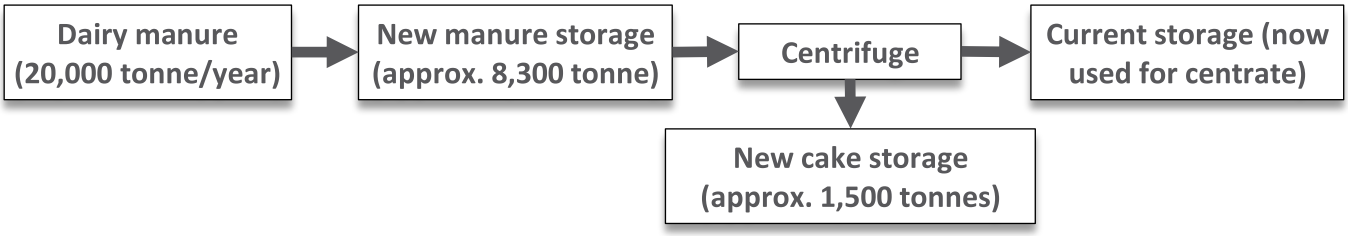
- Farm A process 4 million gallons extra (4m X $0.01 = $40,000). So Farmer A pays Farmer C $20,000 and Farmer D $20,000/year; and

- Farm C process 500,000 gallons extra (500,000 X $0.01 = $5,000). So Farmer C pays Farmer D $5,000/year.

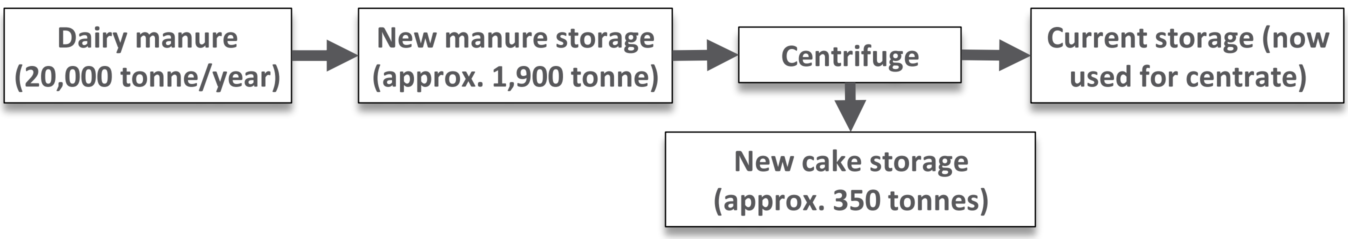
The second factor is storage. B.C. dairy farms typically have one large manure storage pit. This pit would store centrate, while additional storage would be required for manure and cake. The longer the sharing cycle, the greater the requirement for storage. For example, if a farmer uses a centrifuge one month in every six and cake is transported off the farm at the end of the month, he would need five months manure and six months cake storage (Example C). If a farmer uses a centrifuge one week in every six and cake was transported off the farm at the end of the month, he would only need five weeks manure and six weeks cake storage (Example D). For this reason, the shorter the sharing cycle the better

The third factor is performance. Centrifuge phosphorus extraction performance can be impacted by particle size distribution; smaller particles are typically more difficult to separate. Therefore the larger the particle size, all other things being equal, the greater the phosphorus extraction performance. During storage, decomposition occurs which reduces manure particle size. If a farmer uses a centrifuge one month in every six the farm's manure will likely have smaller particles than if the farmer uses a centrifuge one week in every six. For this reason, the shorter the sharing cycle the better.

Example C: One Month Centrifuge Use in Every Six Months



Example D: One Week Centrifuge Use in Every Six Weeks



Sharing a centrifuge between farms could result in the transportation of disease-causing organisms from one farm to the other farms, such as Johne's disease (also known as Paratuberculosis), risking the transmission of these organisms to dairy herds. Because organic matter can harbour infectious organisms, prior to centrifuge transportation all organic matter must be removed. It is therefore very important that joint ownership agreements include clear instructions for cleaning centrifuges before transportation to the next farm.

Centrifuges can be cleaned internally by flushing with clean water prior to shut down through the feed pipe. Appropriate flushing time and water volume varies depending upon centrifuge make and size, and should be discussed with the technology provider. Outflow can be discharged to centrate storage. Externally, centrifuges can be cleaned using a pressure washer. Care should be taken to ensure that all parts of the centrifuge unit are cleaned, including the centrifuge, all piping, and the trailer. Ideally, the area for centrifuge cleaning on each farm should provide access to clean, high pressure water, have adequate drainage, and provide potential to undertake disinfection measures if deemed necessary.

Biosecurity is a two-way process. As such, the receiving farmer can contribute by ensuring that the centrifuge is always delivered by an agreed upon route, minimizing potential for spreading organic matter from the previous farm. The centrifuge should also be used, where possible, away from barns and other animal facilities, and from routes travelled by animals or other mobile farm equipment, such as tractors, skid-steers, wagons, etc. Finally, if at all possible, the farmer should inspect the centrifuge before collecting it or accepting delivery, refusing to do so if it looks unclean or if there are any concerns.

Insurance is an important consideration for joint ownership of a centrifuge. With regards to insuring a jointly-owned centrifuge there are two main options. The first option is to have a single insurance policy for the centrifuge in which all farmers pay an agreed upon percentage of the policy's cost. All farmers would be listed on the policy as Named Insureds and Mortgagees respective to their share of centrifuge ownership. Under this type of arrangement, it is important that all employees, contractors, and subcontractors on the participating farms are covered by WorkSafe, and that there is an agreement in place for paying insurance deductibles.

A potential downside of this approach is that if an insurance claim is required due to an individual's negligence, all farmers may be equally penalised and the claim may impact the insurance rates for every farmer. One way to prevent this from happening is to create an agreement for indemnity provisions that places risk of loss on the farmer at fault. However, this can be difficult to create and potentially contentious to enforce. If this option is taken it is recommended that one farmer be in charge of organizing insurance, as this will be less complicated than several farmers organizing it jointly.

The second insurance option is for each participating farmer to add the centrifuge to their own insurance schedule, as they would rented equipment. This should reduce costs as each farmer can use some of their existing coverage, such as commercial general liability insurance. To reduce costs further, each farmer should only insure the centrifuge for the time it is on their farm. To achieve this, the farmer would notify his insurance company a week or so before the centrifuge arrives, asking for coverage to start on a specific day. When the centrifuge is a week or so from leaving the farm, the farmer would again notify his insurance company, this time asking for coverage to stop on a specific day. Each farmer should provide Certificates of Insurance to other participating farmers, list the other farmers as Mortgagees on the equipment, and be included as additional insureds on each other farmer's policy.

Possible downsides of this approach are that it requires more administrative work for farmers, and in the event of an insurance claim during transit or if it is hard to pin point when damage occurred, there could be a 'he said she said' argument between insurance companies. This would result in companies trying to pin negligence on another party, delaying pay out and jeopardizing the jointly-ownership agreement. Whichever insurance option is taken, it is recommended that each participating farmer first speak with their insurer to determine what they will be comfortable with. Once this is known, all participating farmers can make a joint decision on how they will proceed.

7.4 Contracted Services

While not a form of actual ownership, contracted services have proven popular with many B.C. dairy farmers. Contracted services are when farmers hire a third party to carry out a specific service, and pays for this service based upon an agreed price per volume, distance, weight, time, etc. Agreements can be for a one-time service, or for ongoing service. Good examples of contracted services widely used by B.C. dairy farmers include manure hauling and application, and milk transportation.

Perhaps the greatest advantage of contracted services is that the work is completed by a trained operator. This can be especially beneficial for farms with limited labour, and is more appropriate for complicated equipment, such as a centrifuge. Other advantages include enabling farmers to use a centrifuge without investing a large amount of capital, and potentially having the service provider collect and remove cake from the farm as well. While collection and removal will mean there is no need for additional cake storage, it will likely increase the cost of the service.

7.5 Advantages & Disadvantages

Some of the key advantages and disadvantages of sole ownership, joint ownership, and contracted services are listed below (Table 10). The severity of these advantages and disadvantages will vary from farm to farm depending upon their circumstance and preference.

Table 10: Advantages & Disadvantages of Ownership Options

Advantage	Sole	Joint	Contract
Process manure every day (no additional manure storage required)	✓		
Process manure whenever convenient	✓		
Control over quality of work performed	✓	✓	
Cost are spread, and therefore reduced		✓	
No excess centrifuge capacity (unit cost of processed manure relatively low)		✓	
No responsibility for operating, maintaining, or repairing centrifuge			✓
No long-term investment, likely to be recent model in good condition			✓
No responsibility for liquidating centrifuge if no longer suitable			✓
Disadvantages			
Large investment required, which may have to be paid in only a few years	X		
Unless farm is large, excess centrifuge capacity (unit cost of processed manure relatively high)	X		
If operation or cow numbers change, centrifuge may no longer be suitable	X	X	
Full responsibility for centrifuge maintenance, must pay all repair costs	X	X	
Time to operate and maintain centrifuge can be challenging	X	X	
Long-term investment, unlikely to be recent model in best condition	X	X	
Additional equipment required (i.e., generator and trailer)		X	
Requires work to arrange and potential for disagreement between farmers		X	
Cannot process manure every day (additional manure storage required)		X	X
May not be able to process manure when convenient		X	X
No control over quality of work performed			X
Cost are high due to convenience and service			X

8. Cake Market Assessment

8.1 Local Soil Amendments

Using centrifuges to extract phosphorus from manure can enable B.C. dairy farmers to reduce excess phosphorus levels in their soils. However, this is only achievable if cake is exported off dairy farms and used elsewhere. If B.C. dairy farmers in the Lower Mainland are to find local uses for their cake, it will likely have to replace existing organic soil amendments.[7] The most commonly used organic soil amendments in the Lower Mainland are poultry litter, used mushroom media (UMM), horse manure and compost (municipal and agricultural).

Poultry litter is widely used on crops as a source of nitrogen. UMM, made of poultry litter, gypsum and straw, is predominantly used in topsoil/landscape soil production. Horse manure, most commonly with wood shavings, is used as a soil amendment. Compost, produced with residential food garden, and/or agricultural waste, is used as a potting soil, soil amendment, or as top soil once mixed with sand.

Table 11 shows the key characteristics for poultry litter, UMM, horse manure, compost, and cake for raw and processed manure (without processing) on an as is basis. When compared to other organic soil amendments, cake is wetter than poultry litter, horse manure, and compost, and similar to UMM. Cake has less nitrogen, phosphorus and potassium than poultry litter, UMM and compost (depending on the compost inputs), while it has similar nutrients to horse manure. Finally, the organic matter of cake is lower than poultry litter, compost, and horse manure, and similar to UMM.

Table 11: Local Soil Amendment Characteristics

	Poultry Litter	UMM	Horse Manure	Compost	Raw Cake*	Processed Cake*
Dry Matter	65 – 75	25 – 35	30 – 40	50 – 60	20 – 25	20 – 25
Total Nitrogen	2.5 – 3	0.6 – 1.6	0.2 – 0.4	0.5 – 1.0	0.5 – 0.6	0.5 – 0.6
Total Phosphorus	0.8 – 1	0.2 – 1.1	0.1 – 0.2	0.1 – 1.0	0.1 – 0.2	0.2 – 0.4
Total Potassium	1 – 1.3	0.3 – 1.6	0.2 – 0.4	0.1 – 1.0	0.2 – 0.3	0.2 – 0.3
Organic Matter	30 – 45	15 – 30	25 – 40	30 – 40	15 – 20	15 – 20

8.2 Possible Cake Products

As can be seen from Table 11, cake from raw and processed manure has no clear advantages over poultry litter, UMM, horse manure or compost. As such, it is unlikely to replace these organic soil amendments, especially poultry litter. To create a local market for cake, a clear advantage over these existing organic soil amendments needs to be created. For this reason, value-added processing tests were carried out to determine if cake can be converted into a more desirable organic soil amendment. These tests included composting cake with locally available materials (poultry litter and UMM), mixing cake with sulphur to lower its pH, and oven drying cake.

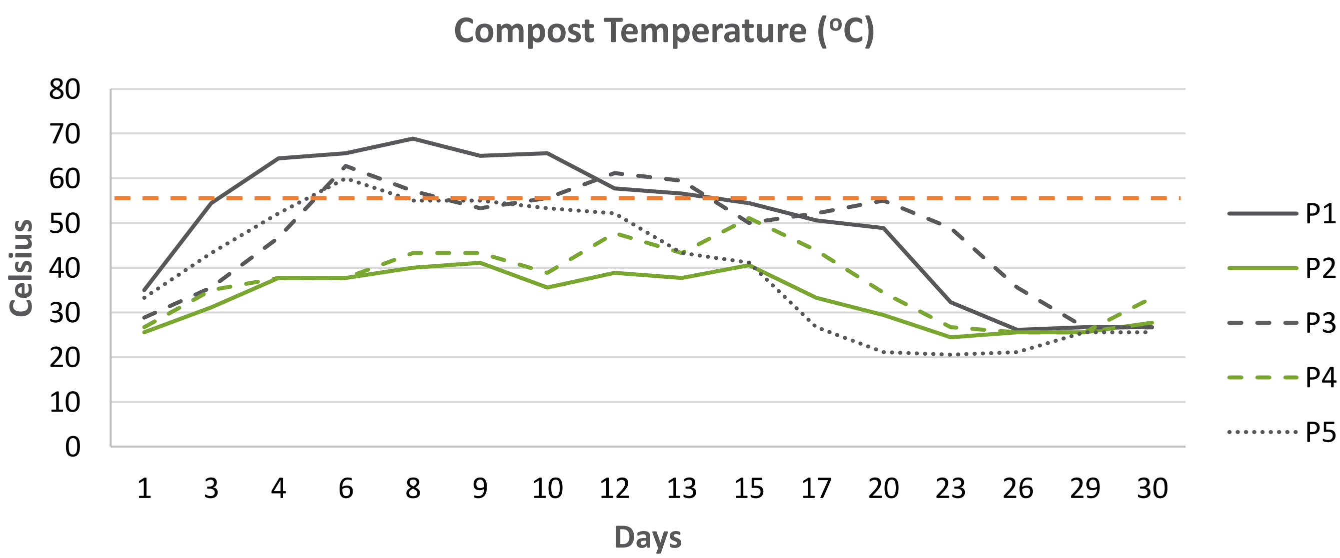
[7] Cake is unlikely to replace liquid or granular fertilizer due to its much lower nutrient concentration, and less desirable physical characteristics (making it unsuitable for spreaders and sprayers).

Composting is a great way to kill pathogens and weed seeds, stabilizes nutrients, and dry cake. To successfully compost cake, a carbon to nitrogen ratio (C:N ratio) of 25 to 30 parts carbon and 1 part nitrogen was required. To utilize locally available agricultural materials, cake was composted with poultry litter, UMM and sawdust to produce five different products:

- Product 1: three parts cake from raw manure, three parts poultry litter, one part sawdust;
- Product 2: three parts cake from raw manure, three parts UMM, one part sawdust;
- Product 3: three parts cake from processed manure, three parts poultry litter, one part sawdust;
- Product 4: three parts cake from processed manure, three parts UMM, one part sawdust; and
- Product 5: one part cake from raw manure, one part poultry litter, one part UMM.

During composting, the temperature of each pile was recorded (Graph 16). Of the five products, three (P1, P3 and P5) reached temperatures >55ºC. Of these, P1 (cake from raw manure, poultry litter and sawdust) achieved the most days >55ºC, followed by P2 (cake from processed manure, poultry litter and sawdust). While these results show it is best to compost cake with poultry litter and sawdust, they also show that >55ºC can be achieved using UMM in place of sawdust (P5).

Graph 16: Temperature for Five Different Compost Piles



Blueberry are widely grown in B.C.'s Lower Mainland. One important requirement for blueberry production is that soil pH levels are kept between 4 and 5. If cake pH can be lowered to <5, it could be widely used by blueberry farms as a mulch and organic soil amendment. To determine how easily it is to lower cake pH, sulphur was mixed with cake from raw manure to produce the following product:

- Product 6: cake from raw manure mixed with 1% elemental sulphur.

Another option for increasing the desirability of cake as an organic soil amendment is to dry it using a mechanical drier; dry cake is easier and cheaper to store and transport. Once dry, cake can also be pelletized or formed into blocks, improving storability and transportability. While potentially expensive, if waste or low cost heat is available (heat as low as 35ºC could be sufficient), drying costs can be significantly reduced. For this study, cake was dried in an oven to produce the following products:

- Product 7: cake from raw manure oven dried to 95% dry matter; and
- Product 8: cake from processed manure oven dried to 95% dry matter.

8.3 Cake Product Analysis

Table 12 shows analysis for the eight cake products (P1 - P8). P1, P3, P5 and P8 are higher in phosphorus than poultry litter, UMM, horse bedding and compost. P1, P3, P5, P7 and P8 are higher in potassium than horse manure and compost, and similar or higher in potassium than poultry litter and UMM. P1 - P8 are higher in nitrogen than horse bedding and compost, similar in nitrogen to UMM, and lower in nitrogen than poultry litter. P7 and P8 dry matter is higher than poultry litter, UMM, horse bedding and compost, while P1 - P6 dry matter is higher than UMM and horse manure, and comparable to poultry litter and compost (dry matter would be 30% - 50% if P1 - P6 weren't composted under cover).

The organic matter of P7 and P8 is higher than poultry litter, UMM, horse bedding and compost, while organic matter of P1 - P6 is comparable or higher than poultry litter, UMM, horse bedding and compost. This is important as organic matter is a critical factor in maintaining/improving soil health and fertility. P1 - P8 are also high in minor elements, such as boron and manganese. This is important as these elements play a meaningful role in crop production and are a key considerations for organic farmers.

The salt content, measured as electrical conductivity (EC), is high for P1 - P6, much lower for P7 and P8.[8] This could be an issue as potting soils require an EC of ≤3. Copper and zinc are also high for P1, P3 and P5 (suggested soil limits for copper and zinc are 150 ppm and 200 ppm respectively). While this makes P1 - P8 unsuitable for use as a potting soil, they should all make excellent soil conditioners and be a good source of organic nutrients, provided they make up no more than 25% - 75% of total growing medium. This shouldn't be an issue in soil or with field crop production.

P1, P3, P5, P7 and P8 have several advantages over UMM, horse bedding and compost. When compared to poultry litter, while P1, P3, P5, P7 and P8 are higher in phosphorus, they are lower in nitrogen. This is important as many horticultural operations land apply poultry litter for its nitrogen content (>2.5%). The nitrogen to phosphorus ratio of P1, P3, P5 and P8 (1 to 1) is also lower than poultry litter (3 to 1), while the nitrogen to phosphorus ratio of P7 (2.5 to 1) is similar. This is important as the 2012 Fraser Valley Soil Nutrient Survey showed that 94% of fields tested had high or very high soil test phosphorus. Application of P1, P3, P5, P7 or P8 instead of poultry litter could exacerbate this issue.

Finally, despite nitrogen in P1, P3 and P5 being more stable and having a slower release rate than poultry litter due to composting (slow nitrogen release extends nitrogen availability and reduces

[8] The EC of manures can be high because of the presence of water soluble nutrients and the use of dietary salts.

leaching, which is particularly important over aquifers with high levels of nitrogen), poultry litter can easily be, and often is, composted once mixed with sufficient carbon to create a suitable C:N ratio.

Table 12: Analysis of the Different Cake Products

	P1	P2	P3	P4	P5	P6	P7	P8
Dry Matter (%)	64	57	68	57	70	71	95	95
Bulk Density (kg/m^3)	310	407	327	503	373	300	100	150
Total Nitrogen (%)	1.6	1.2	1.7	1.1	1.6	1.2	1.9	1.3
Total Phosphorus (%)	1.5	0.7	2.0	0.8	1.5	0.5	0.7	2.0
P_2O_5 (%)	3.5	1.6	4.6	1.9	3.5	1.2	1.7	4.5
Total Potassium (%)	1.4	0.7	1.5	0.9	1.2	0.7	1.6	2.4
K_2O (%)	1.6	0.8	1.8	1.1	1.4	0.8	1.9	2.9
Organic Matter (%)	50	34	51	30	44	51	83	70
pH	7.1	7.2	7.2	7.7	7.0	5.6	8.0	8.1
C:N Ratio	18:1	16:1	17:1	16:1	16:1	24:1	26:1	31:1
Electrical Conductivity (ms/cm)	12.0	10.6	11.3	12.4	12.8	9.2	4.5	6.8
Boron (ppm)	19	11	16	13	20	17	16	17
Calcium (%)	2.42	4.67	2.58	5.33	4.83	2.25	0.80	2.00
Copper (ppm)	213	54	200	58	179	24	27	37
Iron (ppm)	1,117	1,092	1,133	1,217	1,100	675	808	958
Magnesium (%)	0.46	0.35	0.64	0.46	0.62	0.47	0.55	1.20
Manganese (ppm)	363	153	424	183	353	115	174	276
Sodium (%)	0.21	0.09	0.20	0.09	0.15	0.12	0.24	0.16
Sulphur (%)	0.43	1.10	0.37	1.19	1.15	>3.5	0.39	0.50
Zinc (ppm)	305	115	350	134	287	125	151	137

Note: All results shown on an as is basis, and not on a dry weight basis.

8.4 Market Potential

Research was undertaken to determine which Lower Mainland markets P1 - P8 could potentially be used in. Once these markets were identified, large companies within these markets were contacted. During discussion, these companies were asked about their level of interest in P1 - P8, as well as the potential market size and realistic price points for the products of interest.

Soil supply companies blend sand and other fillers with high quality organic material to produce large volumes of landscape soils and soilless growing media. Despite there currently being an abundant supply of organic material from both agriculture (such as poultry litter) and municipalities (residential food and garden waste) in the Lower Mainland, the soil supply companies contacted showed an interest in P1 - P8. If P1 - P8 could be delivered to soil supply companies in the Lower Mainland at a lower cost, approximately \$5/yard (0.76m^3), than competing organic inputs (such as poultry litter, compost and excess dairy manure fibre from solid-liquid separation), it is estimated that this market could use up to 100,000 - 200,000 yards/year (76,000 – 153,000m^3).

Sod supply companies in the Lower Mainland grow grass sod and turf for homes, buildings, sports fields, golf courses, parks, etc. These companies claim to remove very little organic matter, and as such only require fertilizer and lime inputs; any soil that is removed with each harvest is partially replenished through decomposition of the grass roots that remain in the soil. As a result, the sod supply companies contacted showed little interest in P1 - P8. While this may change over time, as scrutiny of the industry's impact on agricultural land increases, currently market potential is minimal.

Sand and gravel suppliers use organic material for top dressing reclaimed gravel pits (a half inch is worked into approximately six inches of soil). One of the most commonly used organic materials in the Lower Mainland is poultry litter; as this adds both organic matter and nutrients to the soil. The sand and gravel supply companies contacted showed an interest in P1 - P8 as they have sufficient organic matter and nutrients for their needs. If P1 - P8 could be delivered to sand and gravel soil supply companies in the Lower Mainland at a lower cost than poultry litter, approximately \$5/yard (0.76m^3), it is estimated that this market could use up to 30,000 yards/year (23,000m^3).

Nurseries and greenhouses use plant growing medium to grow a variety of flowers, plants, shrubs, etc. The majority of the businesses in the Lower Mainland purchase their growing media from local suppliers, with very few making their own. Nurseries and greenhouses parameter requirements for growing medium are very specific, and homogeneity is critically important. Due to the high EC of P1 - P8 (4.5 - 12.8) and specific parameter requirements, the nursery and greenhouses companies contacted showed little interest in P1 - P8. Furthermore, even if these companies did show interest, market size would likely be much smaller than other markets in the Lower Mainland.

There are many horticultural operations in the Lower Mainland growing a variety of crops from vegetables and berries, to trees and flowers. Many of these operations apply approximately 20 - 30 yards/acre/year (15 - 23m^3) of poultry litter. This poultry litter is composted prior to delivery, composted on-site, or land applied raw. Horticultural operations contacted showed varying levels of interest in P1 - P8. For organic vegetable growers with higher nitrogen needs, such as leafy greens, there was interest in P1 - P8 if it could be delivered at a lower cost than poultry litter, approximately \$5/yard (0.76m^3) for raw and \$10/yard (0.76m^3) for composted. However, there were also concerns with the nitrogen to phosphorus ratio of P1 - P8; because this ratio (1 - 2.5 to 1) is lower than poultry litter (3 - 1), land application of P1 - P8 could exacerbate already high soil phosphorous levels.

For organic vegetable growers with higher phosphorus needs, such as alfalfa and root vegetables, there was also interest in P1 - P8 if it could be delivered at a lower cost than poultry litter, approximately \$5/yard (0.76m^3). These operations were also interested in P1 - P8's nitrogen to phosphorus ratio as they often have phosphorus deficient soils. Several berry growers also showed interest in using P1 - P8 as a mulch. However, for these products to be widely used by the berry industry, P1 - P8 would have to be delivered at a similar cost to wood waste products, approximately \$5 - \$15/yard ($0.76m^3$). The potential market size for organic vegetable and berry growers is currently unknown.

Another option is to bag and sell P1 - P8 into the home gardening market. Retail garden centres in the Lower Mainland sell a variety of bagged compost mixes, from low to high end (Table 13). P1 - P8 are as high, if not higher, in nutrients and organic matter than most of these bagged compost mixes, and as such should be able to command a similar price of \$5 - \$10/30 litres (approximately \$125 - \$250/yard). However, the cost to bag and market P1 - P8 will not only be high, but the market size is small.

Table 13: Composition & Price of Bagged Compost Mixes*

	Sea Soil	**Miracle Gro Garden Soil**	**Vigoro Garden Soil**	**ProMix**	**Terra Manure**
Cost	\$7.98	\$9.47	\$6.98	\$8.99	\$5.99
Cost per 30 litres	\$7.48	\$4.98	\$7.48	\$9.63	\$9.40
Total Nitrogen	2.1%	0.09%	0.08%	0.2%	1.0%
Available Phosphate (P_2O_5)	0.21%	0.05%	0.05%	0.1%	1.0%
Soluble Potash (K_2O)	0.06%	0.07%	0.08%	0.08%	1.0%
Organic Matter	63%	15%	15%	40%	50%
Maximum Moisture	54%	70%	70%	N/A	60%

** Note: Guaranteed Minimum Analysis.*

The greatest market potential for cake in the Lower Mainland is as a replacement for poultry litter in soil production, gravel pit reclamation, and horticultural operations with high phosphorus needs. However, for these markets to use cake, it must be delivered at a lower cost than poultry litter. The risk with competing on price with poultry litter is that poultry litter suppliers in the Lower Mainland can also lower their prices; potentially resulting in a race to the bottom as dairy and poultry farmers compete on price to find end uses for their nutrients.

An alternative option is to dry, compress, package, etc., cake and export it to other area of B.C., Canada, or internationally[9]. To achieve as cost effectively as possible, this should occur in large, centralised facilities (thereby utilizing economies of scale) using waste heat where available. However, while this approach could potentially open up new, very large markets and avoid competition with poultry farmers in the Lower Mainland, the costs and risks of doing so will likely be much higher. Furthermore, the financial returns and economic feasibility may be no better than giving cake away locally, as the costs of processing and transportation could erode any additional revenue.

[9] Potential end markets could include Latin America (Caribbean and South and Central America) and South Asia (Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, and Sri Lanka).

9. Feasibility Assessment

Aside from nutrient extraction, centrifuge result in several other benefits. When solids are removed from dairy manure, required volume for long-term storage is less, mixing is easier as settling decreases, power required for pumping is reduced, the ability to pump through small diameter pipes over greater distances is increased, and more manure can be applied to fields during the growing season (increasing crop production). Furthermore, concentrating nutrients into cake means cost of transporting these nutrients between fields is reduced. While these are all benefits, their cost saving are small.

When centrifuges are installed on dairy farms to meet nutrient management regulations, they don't usually generate a profit for the farm. Instead, they are a cost of doing, or even staying in, business. Potential future nutrient management regulations in B.C., which could require greater emphasis on nutrient management planning, may result in B.C. dairy farmers purchasing centrifuges. For most dairy farms centrifuges will not be economically feasible, as capital costs (CAPEX) and operating costs (OPEX) will be greater than any revenues and/or cost savings.

One option for recouping centrifuge costs is through the sale of cake. However, as previously mentioned, expected revenues from cake sales in the Lower Mainland, with or without further processing, are small. Another option is funding. If funding is available, this could offset costs. A third option for recouping centrifuge costs is herd expansion; phosphorus extraction from dairy manure means more manure can be applied to given parcels of land. If centrifuges extract sufficient phosphorus, dairy farmers could increase their herd size without purchasing or rent additional land.

9.1 Centrifuge CAPEX & OPEX

Depending upon centrifuge setup and ownership, CAPEX can include a centrifuge, submersible pump, transfer auger, trailer, manure pit, plumbing, covered building for centrifuge and cake storage, and installation. OPEX can include maintenance and repair costs, electricity, labour, and service costs (Table 14). To estimate centrifuge CAPEX and OPEX several assumptions were made, including:

- Each farm has 150 milk cows (with associated dry cows and heifers), and produces approximately 9,000 tonnes/year of manure (9,000,000 litres or 2,377,548 gallons);
- Each farm captures approximately 1,080 tonnes/year of cake (1,800m^3/year);
- Sole ownership farmer uses a 25 gpm centrifuge for approximately 6 hours/day, 5 days/week. This centrifuge requires 1 hour of labour/day, and uses 15kW/hour;
- Joint ownership involves six farmers using a 50 gpm centrifuge. Each farmer uses the centrifuge one week in every six (requiring each farmer to build a pit for five weeks' manure storage), for approximately 13 hours/day. This centrifuge requires 1 hour of labour/day when on the farm, 8 hours of labour/six weeks for breakdown/move/set-up/etc., and uses 30kW/hour;
- Contracted services are carried out using a 50 gpm centrifuge for one week/month (requiring the farmer to build a pit for one month's manure storage). This centrifuge operates for approximately 9 hours/day when on the farm. Contracted services cost 2.5¢/gallon[10];

[10] This is estimated to be the minimum required for a service provider to achieve an attractive payback on investment.

- Maintenance and repair costs are estimated at 5% of capital cost;
- Electricity costs $0.12/kWh;
- Labour costs $30/hour;
- Centrifuge is purchased using 100% debt with 5% interest payable;
- Average annual inflation is 2%; and
- A contingency allowance, equivalent to 100% of installation costs (manure pit, plumbing, installation, and building), and 30% of operating costs is included to cover unforeseen costs.

Table 14: Estimated Centrifuge CAPEX & OPEX

Estimated Capital Cost	Sole Ownership	Joint Ownership	Contracted Services
Centrifuge	$290,000	$55,000*	N/A
Submersible pump	$7,000	$7,000	$7,000
Transfer auger	$3,000	$3,000	$3,000
Trailer	N/A	$5,000	N/A
Manure pit	N/A	$25,000	$20,000
Plumbing	$2,500	$2,500	$2,500
Installation/set-up	$10,000	$10,000	$10,000
Building	$20,000	$20,000	$20,000
Contingency	$32,500	$57,500	$52,500
Total Capital Costs	***$365,000***	***$185,000***	***$115,000***
Estimated Operating Costs			
Maintenance and repairs	$18,250	$1,542*	N/A
Electricity	$2,853	$2,853	$2,853
Labour	$7,800	$3,900	N/A
Contingency	$8,671	$2,448	N/A
Service	N/A	N/A	$59,439
Total Operating Costs	***$37,574***	***$10,783***	**$62,292**

** Note: costs divided by six farms.*

9.2 Sale of Cake with & without Funding

Recouping investment is called payback. Payback period is the number of years it takes to payback the investment using revenues and/or cost savings. For this assessment, the question is what profit (revenue from sales minus all costs) must cake be sold for ($/tonne), with and without funding, to enable a ten year payback (Table 15).

For sole ownership, cake must be sold for a profit of $75/tonne.[11] This is much higher than realistically possible, even with value added processing such as composting or drying. If funding equal to 100% of CAPEX were available, cake must still be sold for a profit of $35/tonne just to cover OPEX. For joint ownership, cake must be sold for a profit of $30/tonne. Again, this is unrealistic. If funding equal to 100% of CAPEX were available, cake must be sold for a profit of $10/tonne to cover OPEX. For contracted services, cake must be sold for a profit of $70/tonne. If funding equal to 100% of CAPEX were available, cake must still be sold for a profit of $58/tonne.

Table 15: Required Cake Profit

Scenario	Sole Ownership	Joint Ownership	Contracted Services
No funding	$75/tonne	$30/tonne	$70/tonne
100% funding	$35/tonne	$10/tonne	$58/tonne
Increased herd size (no funding)	$37/tonne	$5/tonne	$48/tonne

9.3 Sale of Cake with Herd Size Expansion

As demonstrated in Farm XYZ's NMP, centrifuges can enable B.C. dairy farmers to increase their herd size without having to purchase or rent additional land. Herd size expansion can generate additional profits because the marginal cost of producing one litre of milk is often less than the average cost.

Marginal cost refers to the additional cost of producing the next, additional litre of milk. Marginal cost of milk production is often lower than average cost because some costs don't increase proportionally with each additional cow. For example, when a farmer adds more cows, while the costs of feed, insemination, labour, etc. increase proportionally with each additional cow, other costs, such as machinery, equipment, land, repairs, property taxes, insurance, utilities, quality testing, etc., don't.

According to the Canadian Dairy Commission, the average cost of producing one standard hectolitre of milk in 2015 was $78. This estimate is made up of several costs that will not increase proportionally with each additional cow. Because of this, it is possible that the marginal cost of producing a hectolitre of milk could be 10% lower ($7.8/hectolitre) than the average cost. If a dairy farmer with 150 milk cows increases herd size to 200 milk cows (33% increase), and if each extra cow produces 80 hectolitres of milk/year, the additional profits from these cows could be $31,200/year. If these additional profits are included in the centrifuge feasibility assessment, the profit cake must be sold for decreases.

For sole ownership, cake must be sold for $37/tonne profit to enable a ten year payback. This is a 50% reduction in profit compared to selling cake without increasing herd size. For joint ownership, cake must be sold for $5/tonne profit. This is an 85% reduction in profit compared to selling cake without increasing herd size. For contracted services, cake must be sold for $48/tonne profit. This is a 32% reduction in price compared to selling cake without increasing herd size (Table 15).

[11] Profit is defined as revenue minus all costs associated with cake value-added processing, transportation, marketing, etc.