Evaluating Manure Belt Dryers in Alberta Layer Barns

Final Report

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1.0 Executive Summary

Alberta Agriculture and Forestry (AF) and Egg Farmers of Alberta (EFA) investigated gaps related to benefits, costs and challenges of using manure belt dyers in Alberta layer barns. The main goals for investigation were to understand the following:

- Manure quality as it relates to moisture and nitrogen (N) content
- Economics regarding installation and operation of belt dryer systems
- Air quality as it relates to in-barn ammonia (NH3) and dust levels

Theoretically, the drying of freshly excreted manure reduces ammonia-nitrogen (NH3-N) volatilization, resulting in a higher concentration of N in the manure. To test this theory, nine scenarios were developed based on benchmarked Alberta egg production operating practices. This study involved two layer barns: an aviary (Farm A) and a furnished (Farm F) barn. Key variables monitored during a summer (2017) and winter (2018) period included in-barn NH3 levels, manure moisture and nutrient content, in-barn dust levels, and energy use by the manure belts and dryers. Data collected based on the key variables were correlated with the scenarios for analysis.

Manure drying provided up to a 50% reduction in maximum NH3 concentrations during some scenarios in the winter testing. Monitoring found higher in-barn NH3 concentrations during the winter months as compared to the summer months. However, results suggest that to minimize in-barn concentrations, increasing the frequency of manure removal was more effective than drying.

Results from the summer testing suggest that manure moisture content was affected by barn temperature, humidity and ventilation more than by manure drying on Farm A. On Farm F drying resulted in a significant reduction in moisture content. Manure drying tests in the winter resulted in significant manure moisture reductions at both farms.

Statistical analyses indicated there were no significant trends in the N results from either farm. However, it is possible that some level of N was retained, taking into consideration the reduction of in-barn NH3 reported and small increases in N content. To quantify retained N, a more controlled study would be necessary to compare scenarios simultaneously. This would remove some variability introduced by the scale of a commercial barn.

Dust levels in the two barns were comparable to levels found in other studies in the United States. Data trends from both farms show a strong correlation between bird activity and dust levels. Data did not suggest that dust levels increased with the use of manure belt dryers.

Energy and power usage by the dryer fans and manure belts were monitored in both barns. The energy consumption of the manure belts during removal is minimal compared to the power use of the dryer fans. Thus, more frequent manure removal would be a more economical option than operating the manure dryer.

Economic analyses of manure belt drying indicated annual gross revenue was heavily influenced by N content of the manure and total manure produced. Analysis of the average annual cost, on a per bird basis for both farms, indicated 1-day removal frequency results in the highest cost due to increased labour and hauling requirements as compared to the 3- and 7-day removal frequencies. Marginal net operational gains (considering the market benefit of the manure N against the operational costs) were found at both farms for the 7-day removal frequencies, with the no drying scenario providing the highest gain.Net present value (NPV) improved as the number of days between manure removal increased due to the larger volume of manure over the cost savings of lower labour and hauling costs. However all scenarios resulted in a negative NPV.

Daily manure removal resulted in the lowest in-barn NH3 concentrations. However, based on economic analyses, the cost in terms of labour and equipment use for daily removals made manure removal at three days with no drying the optimum choice for realizing the benefits of reduced in-barn NH3 while balancing labour and equipment inputs.

For producers that have invested in belt drying systems some recommendations were made based on research findings to improve efficiency and reduce operational costs. The operation of a belt dryer may be beneficial to the producer:

- At the onset of a new flock cycle, as results showed the manure moisture content was higher compared to that of an older flock, which can lead to higher in-barn NH3 levels. Using a belt dryer until the flock has reached peak production can reduce manure moisture content and ambient NH3 levels.
- If feed rations have added salt for the reduction of pecking and bullying. Higher salt in the ration likely increases the moisture content of the manure so using the manure dryer can reduce manure moisture content.
- If a producer is using a cooling system during the summer months, the in-barn humidity may increase resulting in higher manure moisture content. With misting systems in particular, the manure nearest the cooling system will likely have higher moisture content. Running the manure dryer while the misting system is operating can reduce manure moisture content and prevent increased in-barn NH3.

The in-barn testing resulted in additional findings. In-barn NH3 sensors were not consistently accurate and did not respond quickly to changing barn conditions. Continuously installed in-barn sensors should not be relied on to be accurate without frequent calibration and other technologies, or other methods should be investigated as alternatives.

Although producers see a value in the manure as a crop amendment, most were not as concerned with the final nutrient content of the manure as they were with in-barn air quality and manure weight or initial transportation costs. The perceived purpose for drying manure was to reduce NH3-N loss and thereby improve in-barn air quality. Other purposes were the N content of the manure as well as reducing the moisture content and therefore the weight of the manure, thereby reducing transportation and application costs. Producers were operating the dryers to dry the manure, and then transport that manure from the barn to an uncovered field or yard storage site until the manure was spread. The stored manure would be exposed to the elements, absorbing moisture thus negating some of the benefits achieved by the drying (a lighter product and better NH3-N retention. It appears the benefit of manure dryers end when the manure leaves the barn and is piled in the field. To get the maximum value of the dried manure, it must be stored in covered storage to reduce moisture absorption and N lost to the environment.

In summary, manure belt dryers are a management tool. When producers are deciding whether to invest in a manure dryer system, they should consider:

- how they operate their barn,
- whether they have limitations in time and labour,
- if there are any conditions in particular they have to deal with or would like to manage differently, and
- how they manage manure after it leaves the barn.

Results show that manure dryers can reduce manure moisture content, thereby reducing in-barn NH3. However, results also show that simply increasing the manure removal frequency has more impact, in terms of reducing in-barn NH3, than manure drying. Also, if manure N is valued, manure management and handling after the manure is removed from the barn becomes more important.

It became clear during the course of the project that making the decision on whether to invest in manure drying systems or not comes down to personal preference regarding in-barn conditions and management.

2.0 Industry Background

In recent years, poultry producers have been moving away from traditional styles of animal housing due to increased social pressures regarding animal welfare and occupational health and safety. The European Union (EU) Council Directive set forth in 1999 stipulated that poultry laying hens housing from 2012 onward may only be housed in either furnished cages or non-cage systems [1]. Very recently, Tesco, a supermarket chain who is the world's third largest retailer, has pledged to cease sale of eggs from caged hens in all of its central European stores beginning in 2025. This is an expansion on its pledge from 2016, banning cage-eggs in its United Kingdom (UK) supermarkets [2]. Locally, an announcement by Egg Farmers of Canada outlines the transition away from conventional housing to furnished, free-run, or free range aviary housing by 2036 [3].

In conjunction with these changes to hen housing, changes are also being made regarding in-barn manure management. The changes in manure management are also being driven by concerns regarding animal and worker welfare, of which in-barn NH3 is a large concern. Elevated NH3 can be linked to respiratory issues in both exposed birds and humans working in the barn environment, and can cause reductions in layer egg production.

Numerous studies have been conducted to identify control mechanisms for in-barn NH3 reduction and there are recommendations promoting the shift from traditional deep pit or high-rise housing to barns with manure belt systems. Installation of these new systems requires an infrastructure change and a substantial capital investment by producers. However, when considering the increase in social concerns regarding bird health and jurisdictional changes stipulating which housing systems are deemed acceptable for egg production, poultry producers are seeing this shift to manure belt systems as the way of the future. By adding dryers to work in conjunction with the manure belts, egg producers potentially have the opportunity to reduce NH3 emissions, improve in-barn air quality, and maximize nutrient quality of manure.

3.0 Alberta Perspective

In a 2012 report commissioned by EFA, the following recommendation was put forth:

- EFA promotes and supports installation of both belt and drying systems on egg producing farms, as well as investment in sheltered manure storage facilities to minimize nutrient loss to the atmosphere [4].

This recommendation generated interest in adopting manure belt drying systems. In 2013, EFA developed the manure management section of EFA's Producer Environmental Egg Program

(PEEP). They also approached the AF Growing Forward 2 – Confined Feeding Operation Stewardship Program to determine whether the program would fund the purchase and installation of manure dryers on Alberta layer and pullet operations.

PEEP, an on-farm environmental program for egg producers, was launched in 2014. It was based on the Alberta Environmental Farm Plan (EFP) but was tailored to reflect production practices and considerations on poultry layer operations. The program allows producers to identify their impacts on the environment, as well as provide suggested practices to reduce those impacts. Producers can receive a score, with 60% considered a passing mark. Since launch, scores have remained relatively low in the manure management sections of PEEP, which has emphasized a need to address extension activities related to practices, such as manure handling, storage and application.

After discussions with EFA about their enquiry for funding and PEEP results, AF commissioned an investigation into the use of manure drying belts in layer barns [5] in 2015 to learn more about what was known about the present systems. Several areas were highlighted in which further investigation was deemed essential in terms of both manure management research and extension needs. In order to help fill these information gaps, AF's Environmental Stewardship Branch and Egg Farmers of Alberta (EFA) initiated this project. The project goal was to understand all the benefits and challenges to adopting manure drying systems in Alberta. The investigation included the following:

- Manure quality as it relates to moisture and nitrogen (N) content
- Economics regarding purchase and operation of belt dryer systems
- Air quality as it relates to in-barn ammonia (NH3) and dust levels

4.0 Literature Review

To provide understanding and context for the project's in-barn testing, and variables for consideration, a literature review was done.

4.1 Ammonia Production

Various aspects of poultry production can influence NH3 production, such as housing design, bird age and health, drinker management and maintenance, litter age and management, and outside weather conditions [6]. During egg production, the hens, via feed, consume large amounts of N. The birds, for growth and egg production, utilize a portion of that N, while unused portions are excreted. The N is excreted in the form of uric acid, which constitutes approximately 50% of the freshly excreted manure. Ammonia is produced from the hydrolysis, mineralization and volatilization of the uric acid. There are four main factors that contribute to NH3 formation [7]:

- manure or litter pH
- nitrogen content of the manure or litter
- manure or litter moisture content
- barn temperature

Ammonia production increases when the manure pH is over 7, with high production occurring at a pH of 8 or greater. The typical pH of manure and litter is between 7.5 and 8.5, respectively. In terms of N content, it has been estimated that 50-80% of the N in manure is converted to NH3. At moisture content (MC) between 40-60%, NH3 losses generally increase, while values below 40% MC generally reduce the release of NH3. Indirectly, barn temperature also greatly affects NH3 release, particularly between 20-30°C where sharp increases can be seen [8].

Producers may use three strategies to control NH3 production:

- ventilation management
- dietary manipulation
- manure management

Of these three strategies, manure management is the most commonly used method [7].

4.2 Impacts of Ammonia

In-barn NH3 emissions can affect bird and worker health, it has a distinct odour at low concentrations, and at moderate levels can cause eye and respiratory irritation [9]. Table 1 shows health impacts at different concentrations of NH3.

Table 1. Health effects in relation to concentrations of ammonia [9].

Concentration (ppm)[z]	Health Response
24 – 50	Nose and throat irritation after ten minutes of exposure
72 – 134	Irritation of nose and throat after five minutes exposure
700	Immediate and severe irritation of respiratory system
5,000	Respiratory spasms, rapid suffocation
Above 10,000	Pulmonary edema, potentially fatal accumulation of fluid in lungs

[z] *ppm is an abbreviation for parts per million.*

In most environmentally regulated livestock buildings, 10 to 20 ppm are typical levels of NH3 with liquid manure systems, and 50 ppm where solid manure is handled. In poorly ventilated buildings, particularly with lower winter ventilation rates, NH3 levels can exceed 50 ppm and reach 100 to 200 ppm.

Exposure to high NH_3 concentrations can cause damage to the mucous membranes of the respiratory systems and eyes of laying hens. Higher concentrations can also have negative impacts on overall liveability, weight gain, feed conversions and bird immune systems [10]. It has been suggested that exposure to 20 ppm for long periods of time can result in a variety of disorders, including increased disease susceptibility and respiratory tract damage [7]. According to the Code of Practice for pullets and laying hens [11], birds can detect at NH3 at 5ppm and find it aversive at 20 ppm. Producers are required to take action to manage NH3 levels if they reach a harmful range (20 to 25 ppm).

There are significant respiratory hazards for workers exposed to NH3 for long periods at concentrations higher than 25 ppm. Several agencies publish guidelines and suggest limits to NH3 exposure intended to protect human health and safety. The American Industrial Hygiene Association (AIHA), the American Conference of Governmental Industrial Hygienists (ACGIH) and the National Institute for Occupational Safety and Health (NIOSH)), recommend an exposure Threshold Limit Value (TLV) of 25 ppm of NH3 (based on an 8-hour time weighted average).

The TLV for NH3 gas in Alberta (based on the guidelines above) is:

- 25 ppm for long term exposure (8 hours)
- 35 ppm for short term exposure (15 minutes)

4.3 Housing and Manure Management Systems

As of 2016, approximately 90% of Canadian laying hens are housed in conventional (battery cage) housing systems, with the remaining 10% housed in a combination of furnished, free-run, or free-range aviary production systems [12]. Comparison of housing systems with corresponding manure collection and handling systems are shown in Table 2.

Conventional housing consists of rows and columns of identical cages connected together sharing a common divider wall [13] made of wire mesh and sloping floors typically housing 4 to 8 hens [14]. Furnished cages are larger than conventional cages and can vary in population from 10 to 100 hens in each cage. In addition to being larger, they provide “furnishings” such as nesting boxes, scratch pads, and perches.

While the layout of cages vary, with several different set-ups in the industry, manure belts can be combined with most systems. The manure belts are located under each tier of cages in a caged system or under the perches and nesting boxes in the tiered aviary systems. Freshly excreted manure drops onto the belts and can dry naturally by ventilation air or by forced-air directed through air ducts under the cages and over the surface of the manure (manure belt drying). The manure on the belts is then be conveyed to one end of the barn for removal.

The drying of the manure, naturally or by forced air, results in the removal of moisture reducing the chemical and biological processes that promote emissions [15].

Aviary systems, can be free-range (access to outdoors) or free-run (enclosed barn) housing systems, allowing the hens to roam freely while also providing a multi-tiered system of nesting boxes and perches [16]. Aviary systems may or may not have manure belts incorporated into the tiered systems. In aviary barns equipped with manure belts, the age of the hens generally dictates the amount of manure that is dropped in the litter and on the manure belts. At 20 weeks of age, almost 50% of the manure is deposited in the floor litter and by 30 weeks of age only 10-15% of manure is dropped in the litter (85-90% dropped on manure belts) [17]. There are advantages and disadvantages to each of these housing systems.

Table 2. Summary of housing systems with corresponding manure collection and handling systems and typical removal frequencies.

Housing system	Caged system	Manure collection	Removal frequency
High rise	Yes	Pit storage	Periodically or annually
Conventional	Yes	Manure belts	Varying [z]
Furnished	Yes	Manure belts	Varying [z]
Aviary (free-run)	No	Manure belts, floor litter	Varying [z]
		Floor litter	Periodically or annually
Aviary (free-range)	No	Manure belts, floor litter	Varying [z]
		Floor litter	Periodically or annually

[z] From daily to once or twice per week

4.4 Poultry Manure Profile

Poultry manure nutrient concentrations and moisture content can vary depending on several factors including the housing system and conditions, feed ration, age of birds, and manure handling and storage. Generally, N and carbon (C) in manure decline with time, while other nutrients such as phosphorus (P) become more concentrated [18]. Freshly excreted manure has high moisture content (~75% moisture) as well as high N content, which declines as a portion of the N (50 to 80%) is converted to NH_3 and lost to the atmosphere. However, if the manure can be dried within 50 hours after excretion to below a moisture content of 40% [19] there will be minimal losses in the form of NH_3, meaning higher levels of N will be retained in the manure.

Poultry manure generally contains higher nutrient concentrations in comparison to cattle or hog manure, thus the economic value of the manure is higher. Typical nutrient contents of total nitrogen (TN) for poultry layer manure in southern Alberta range from 50-70 lbs/ton with MC ranging from 30-60% [20]. A similar value is used in Manitoba, with an average total Kjeldahl nitrogen (TKN) of 46 lbs/ton and average MC of 65% [21] for layer manure. In Kansas, a study comparing lab analysis of 67 poultry manure samples found an average N content of 55 lbs/ton [22]. As a limited number of producers in Canada are using manure belt dryers, averages for dried manure have not yet been reported.

4.5 Manure Drying Options

There are two main types of manure drying systems for manure belt barns: in-barn and external systems. In-barn manure drying has perforated ducts that run above the belts and direct air over the surface of the belts. The air is driven by an external fan that draws air from either inside or outside the barn. In-barn belt drying systems used with cages must be installed at the time the cages are installed, and cannot be retrofitted to existing systems.

Comparatively, external manure drying systems dry the manure after it has been removed from the belts under the cages and conveyed out of the barn. After the manure is removed from the barn, it is distributed evenly as a thin layer on a multi-tiered conveyer system. The manure passes through the different tiers over a set period of time so a consistent amount of drying can be achieved for all the manure. The manure is generally dried by warm, barn exhaust air blowing through the tiered system. The manure is dried for a consistent length of time and can be dried to a moisture content of 10-30%. Depending on the type of system and the desired final moisture content, drying can take 3-5 days. In order to achieve effective drying, one manufacturer recommends 2 m^3/hour per bird of airflow through an external dryer [23]. However, in the winter, minimum ventilation rates can be set as low as 0.6 m^3/hour per bird when ventilation is used to control in-barn carbon dioxide levels [24]. Therefore, minimum ventilation rates in the winter months may not provide enough airflow for optimal manure drying in external systems. External drying systems are generally considered to be more effective than in-barn systems, but have higher capital costs.

In-barn manure belt drying systems generally have a lower capital investment, but the manure cannot be dried as consistently. Since drying takes place directly under the birds, the manure on the belt is dried from the time it is excreted until the belts are emptied. The amount of drying can vary from no drying to multiple days depending on when the manure was excreted to when it was removed from the barn. Some of the reasons for the limited wide scale adoption of manure drying systems include capital and operating costs, uncertainties regarding impact on in-barn dust levels, and effectiveness of drying in different seasons and weather conditions in Alberta.

4.6 Ventilation Considerations

Literature shows that the starting, as excreted, moisture content for laying hen manure is approximately 75% moisture content (MC) on a wet-basis (WB). During drying, liquid water in the manure transforms into water vapour and enters the barn air contributing to the relative humidity of this barn air. This liquid-to-vapour conversion (drying) happens at all temperatures as long as the air relative humidity is less than 100%, because the vapour pressure at the liquid interface is higher than the vapour pressure in the air. Lower moisture content of the manure on the belt, means there was more water vapour added to the barn air over the period. When the additional water vapour (dried from the manure) brings the barn relative humidity above the barn humidity set point, the control system will activate the general barn ventilation system to exhaust the higher humidity barn air and bring the barn air back down to the humidity set point.

In Alberta, summer ventilation, and generally spring and fall ventilation, is based on minimizing temperature rise in the barn. The ventilation rates used to minimize temperature gain are notably higher in scale than rates used to maintain humidity. Therefore, increases in relative humidity in the barn during summer tend to be insignificant and temporary, except for occasional days where outdoor humidity may also be high, as the ventilation rate for temperature already manages the typically occurring humidity range, almost as a side effect.

Winter ventilation on the other hand is typically set based on maintaining a maximum set relative humidity, and is occasionally set to limit carbon dioxide concentrations. This ventilation rate generally accounts for moisture produced from the respiration of the housed animals, and from manure, wash water, or other sources of liquid water. When barn air is exhausted, an equivalent amount of fresh outdoor air is required to be brought into the barn through the inlets. During the winter, this incoming fresh outdoor air must be heated to the temperature set point of the indoor barn air. For typical production scenarios inside the barn, there will be minimum expected ventilation, with expected matching heating requirements that vary day to day based on actual outdoor conditions. In other words, there is a baseline for expected winter ventilation and heating. Management factors that change the indoor environment during winter, such as introducing more moisture into the air from the drying, will increase ventilation and heating rates. This increase can be compared to the baseline. It is also worth noting that manure at 75% MC is difficult to handle with belts and trucks. From a practical point of view, ease of handling improves at moisture contents of 65% and below.

4.7 Manure Handling, Storage and Nitrogen Emissions

The potential for N loss does not stop once the manure leaves the barn and how the manure is handled and stored determines the potential for losses. The most effective method of reducing

NH_3 losses is to land apply and incorporate as quickly as possible, however this is not possible for a large part of the year. There are a variety of ways to store solid manure and Table 3 provides estimated N losses for manure storages in Canada [25].

Table 3. Percent nitrogen loss from various storage systems [25].

Storage System	Housing	Storage	Total
		N loss (%)	
Open pile, on ground, no roof	5	20	25
Open pile, on ground, roof	5	15	20
Manure pack (barns, pens or corrals)	5	10	15
Open pad, without runoff containment	5	15	20
Open pad, runoff containment	5	8	13
Covered storage pad	5	4	9

5.0 Baseline Alberta Testing

In the summer of 2016, a phone survey was conducted with 31 egg farmers across Alberta. The goal was to survey egg producers operating manure belts in order to establish a benchmark of operating practices in Alberta. From this initial survey a number of producers, those using manure belt dryers, were selected for more in depth study. Barn observations and manure samples were collected at 15 farms to investigate their drying systems in general, as well as system effectiveness. Manure samples were collected from those 15 barns from October 2016 through January 2017. Of those barns, 5 had furnished cages, 7 were conventional and 3 were aviary.

5.1 Moisture Content in Alberta Barns

From the baseline, manure testing, large variation was observed in the moisture contents (MC) of the different systems. Dried manure was collected from the belts as the manure was removed from each barn at the farm's regular removal schedule. One hour after the removal of the dried manure, the belts were run again to get a comparative fresh manure sample to evaluate the amount of drying that occurred on the belts. The MC of the fresh manure ranged from 70%-78%. The dried manure had a larger range with MC ranging from 36%-66% (Figure 1).

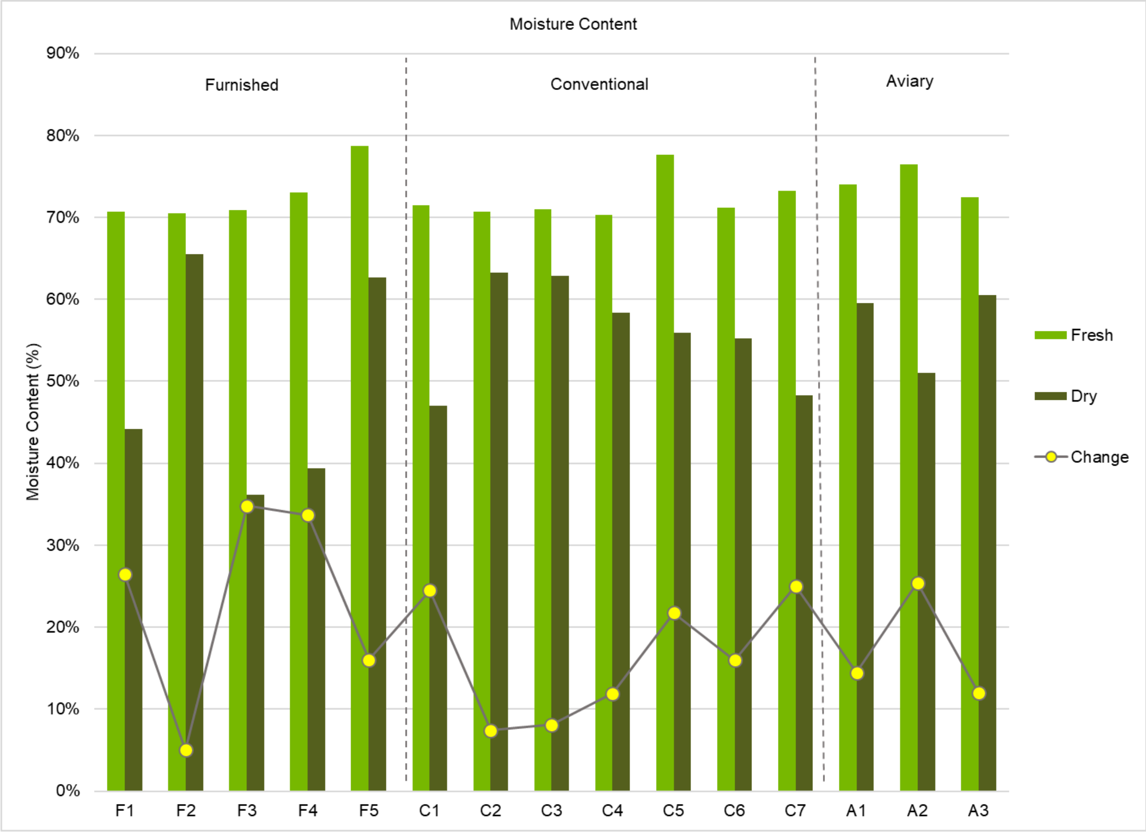

Figure 1. Moisture content of poultry manure from furnished (F), conventional (C) and aviary (A) barns with manure belts showing the Fresh (freshly excreted) and Dry (standard removal time) manure moisture contents.

The range of moisture levels indicates there are a number of variables that may affect MC in addition to manure drying. During the farm visits it was found that four of the barns did not in fact have forced air drying (thus the zero hours of drying), and the manure removal frequency varied from three to seven days across the 15 barns, therefore each barn had a different amount of total drying (Figure 2). Some barns had less MC reduction than would be expected, possibly a result of various factors including smaller drying systems, high in-barn relative humidity and shorter manure removal times. These factors were used to develop testing scenarios, as well as select cooperating producers for an in-depth evaluation.

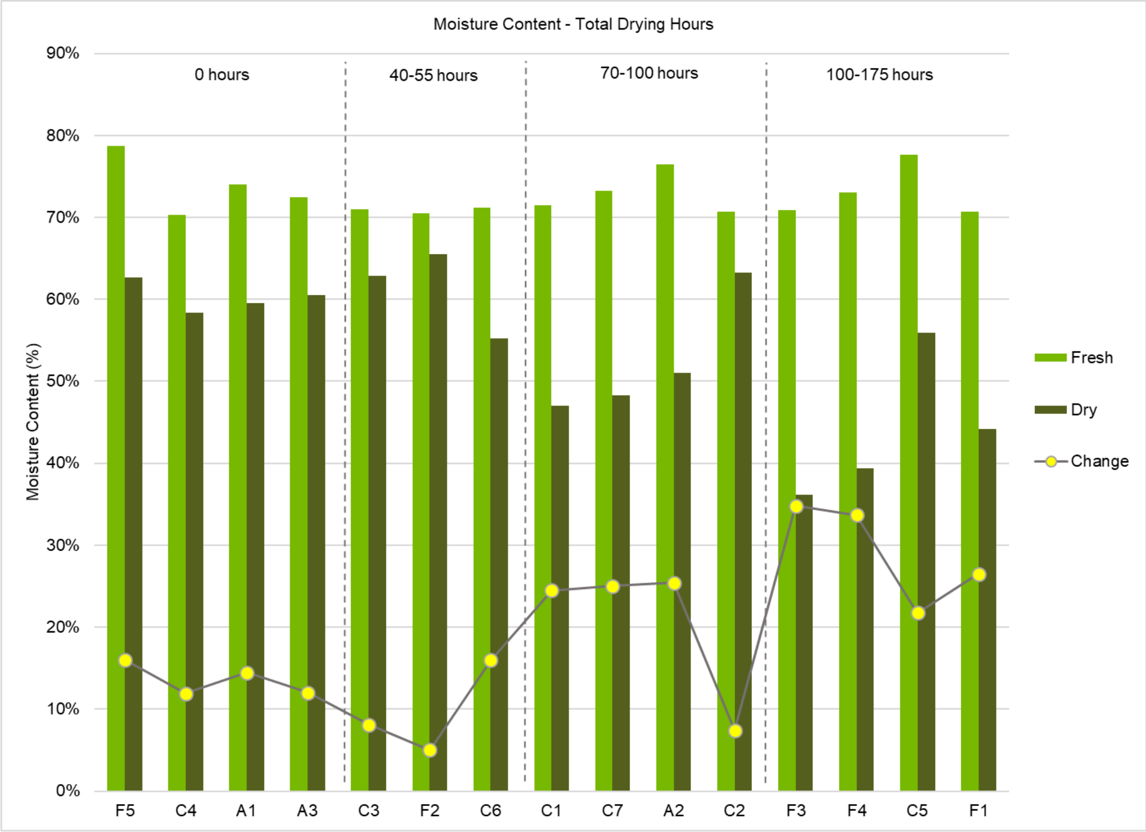

Figure 2. Moisture content of manure based on number of drying hours from furnished (F), conventional (C) and aviary (A) barns.

5.2 Nitrogen Content

The N content of the 15 samples collected (Figure 3), determined by lab testing, did not meet the theoretical assumption that freshly excreted manure (collected after a one-hour period) should have higher N compared to manure exposed to air for a longer period of time, which would increase losses due to volatilization. N values ranged from25-105 lbs/ton (4.0-10.2% w/w). When comparing values for the Fresh and Dry samples, there was noteworthy variability with the Dried samples often having higher levels of N than the Fresh samples. This variability could have been attributed to a number of factors including inconsistent manure sample collection, handling, processing and analysis. Although the N values could not be used for relevant nutrient analysis for the baseline testing, they provided key learnings for further manure sampling and handling protocol development for the in-barn testing.

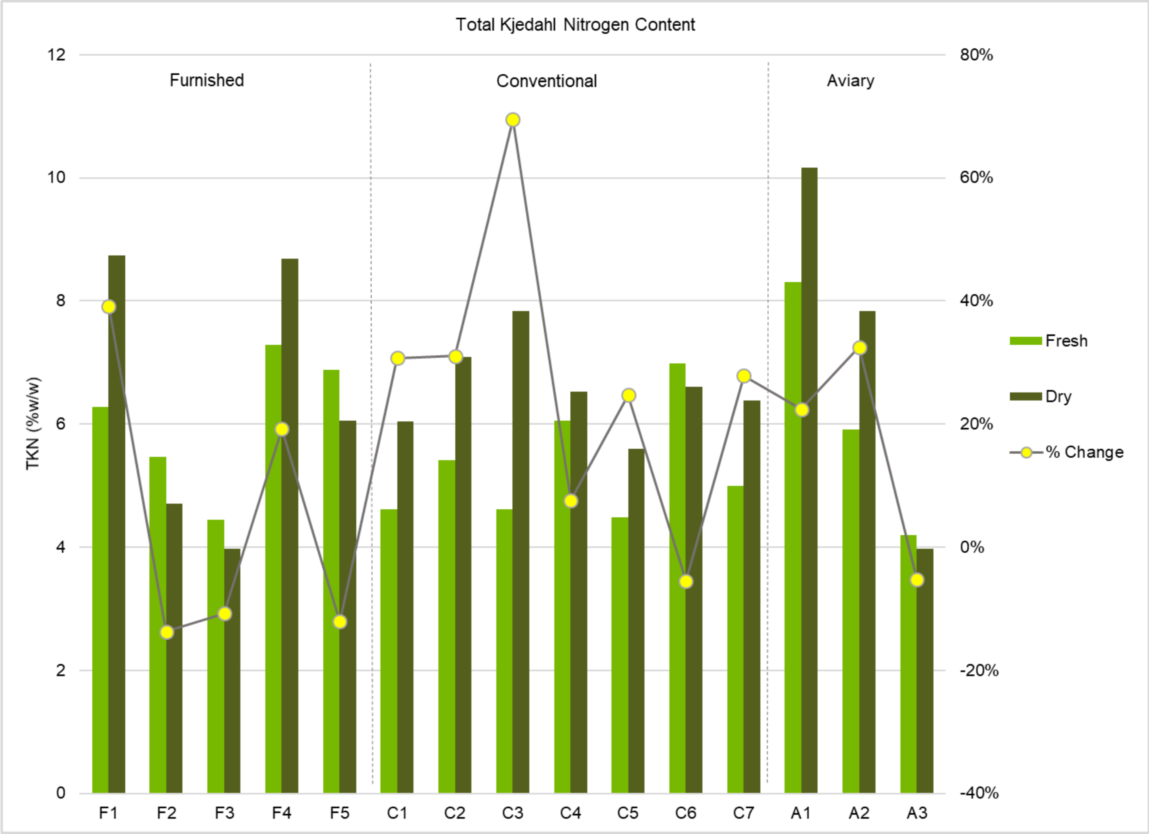

Figure 3. Total kjedahl nitrogen content of manure from furnished (F), conventional (C) and aviary (A) barns visited for the baseline testing.

6.0 In-Barn Testing and Procedures

From the baseline sampling, only manure belt housing systems with drying were considered for further testing in this project. Testing was done in an aviary (free-range) barn and a furnished barn. For this report, the two barns will be referred to as Farm A (aviary) and Farm F (furnished).

Due to the extreme differences in Alberta seasons, periods of testing were conducted in both summer and winter. In summer, high rates of ventilation lead to warm drying air and relatively low humidity. Comparatively, in winter, ventilation is often at minimum rates resulting in higher in-barn humidity. As a result, the available drying air will likely either be colder if taken from outside or will be of higher humidity if taken from in the barn. Therefore, there are unknowns about the effectiveness of manure drying in the winter. As well, due to the difference in ventilation rates, the barn NH_3 levels could be expected to be more concentrated in the winter than the summer months.

6.1 Barn and Drying System Configuration

Though the two farms have very different setups, both have belt drying systems. The barn at Farm A is split down the center into two barns, each with flocks of different ages. Only one side of the barn was involved in the study for biosecurity reasons. This barn is 293 ft long x 34 ft wide, has two rows of nesting areas, with each row having two tiered belts. Farm A has a maximum capacity of 20,000 birds (in the barn selected for study); during the summer testing period it housed approximately 16,200 Lohman brown birds. At the beginning of the winter testing period there were 15,578 birds housed. The flock was 24 weeks in age at Farm A at the onset of summer testing, and 56 weeks at the beginning of the winter testing.

Comparatively, the barn at Farm F has four rows with five tiers of cages each and is 96 ft long x 44 ft wide. Farm F has a maximum capacity of 12,162 birds and housed approximately 11,952 Lohman brown birds during the testing period, with a flock age of 40 weeks. The winter testing at Farm F began just after a new flock (18 weeks old) had been housed, which consisted of 12,160 birds.

Drying and ventilation systems varied between the two barns. Farm A's dryer has a 4 horsepower (hp) electric motor and a centrifugal fan. The fan provides approximately 4250 cubic feet per minute (cfm) of airflow over 4 belts, or approximately 0.25 cfm/bird [26]. The dryer at Farm F has a 7.5 hp electric motor and was designed to provide 0.5 cfm/bird. Both barns have radiant fin heating to maintain temperature, but only Farm F has a misting system for cooling in the summer. Farm F draws its inlet air through ceiling inlets down the centre of the barn and exhausts the air out both sides. During the warm summer months, portable circulation fans are mounted in-between the rows near the barn floor. Comparatively, Farm A draws air in through the ceiling and has mixing fans to circulate the inlet air and has exhaust fans that remove the air upward through the roof.

6.2 Testing Scenarios

Nine scenarios were planned for both farms to test manure drying effectiveness resulting from different drying hours and manure removal frequency (Table 4). The scenarios were developed based on information provided by baseline data collection. Twenty hours of drying was chosen to reflect the average number of hours' producers were currently using their systems. To assess the impact and efficiency of the dryers, 10 hours and no drying were chosen for comparison purposes. In terms of manure removal, the majority of producers were removing the barn manure every seven days, with a few others emptying twice per week. Again, the removal frequency scenarios where chosen to reflect current practices in Alberta, with the one-day removal acting as a baseline for comparison purposes.

Table 4. Scenarios used to test manure drying effectiveness.

Drying Time	1-Day Removal	3-Day Removal	7-Day Removal [z]
No drying	Nd1	Nd3	Nd7
10 hours	10h1	10h3	10h7
20 hours	20h1	20h3	20h7

[z] During winter testing the seven-day removal scenarios were dropped to six days due to high in-barn ammonia levels.

Scenario Nd1 was the starting scenario at both farms and was repeated at the end to determine if there were any changes over the testing period that may be attributed to hen age, diet or barn conditions.

6.3 Data Collection

Throughout the study, in-barn temperature, barn humidity, outside temperature, outside humidity, and ventilation rates were measured and logged to determine potential impacts on manure dryness. Ammonia and dust levels were also measured in the barns to determine if there was an impact related to manure drying. Other parameters such as water and feed consumption, egg production and mortality rates were all collected to ensure there were no impacts on bird health and production from the scenario testing.

Temperature and humidity readings were used from sensors already installed in the barns. Instantaneous readings were collected with handheld sensors and compared to the barn sensors to ensure proper calibration. Dust readings were measured and logged with Dylos DC1700 Air Quality Monitors providing particle counts for two ranges of particle size; particles greater than 0.5 microns (small) and for greater than 2.5 microns (large). Both barns have NH_3 sensors (of the same make) installed to log NH_3 levels, but instantaneous readings were taken once per day to correlate logged data. The instantaneous readings were taken with RAE gas detection dosimeter tubes (range 1-30 ppm) (Figure 4). The NH_3 sensors were located in the centre of the barn, suspended from the ceiling, approximately four feet from the ground. The instantaneous readings were taken at the in-barn NH_3 sensors when collected. Dust monitors were located in the centre of the barn as well. At Farm F, the dust monitor was placed under the NH_3 sensor, approximately two feet off the floor. At Farm A, the dust monitor was fastened with wire mesh to a barn divider near the wall (nearest power outlet) approximately four feet off the floor.

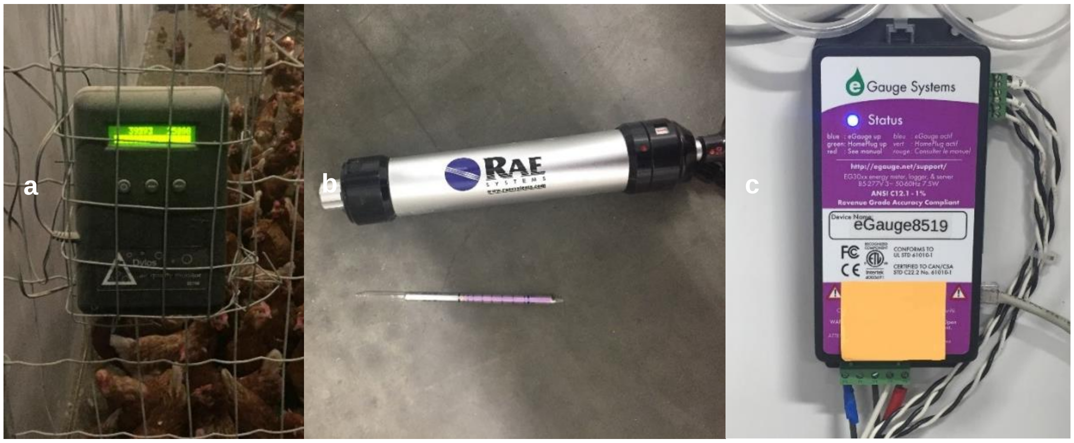

Figure 4. Dylos DC1700 dust monitor (a), RAE hand pump and dosi-tube (b), eGauge sub-meter (c).

Electricity usage was measured for the drying fan and the manure removal belts. Two eGauge EG30xx sub-meters were used at each farm with appropriate current transformers (CTs). At Farm A, each row of belts was measured separately as well as the cross conveyer. The cross conveyer brought manure from the main belts to the discharge conveyer that dropped manure into a truck. At Farm F, there was only metering capacity for 2 of the 4 rows of belts (only 10 of the 20 belts were monitored), so a calculation was completed to estimate total power.

Manure was sampled at the end of each scenario at a similar time in the morning. Samples were taken from the main collection belt (that collected manure from all the individual belts throughout the barn) for the duration of time it took to empty the barn, during which feathers and egg shells were removed from the manure (Figure 5). After collection, the manure was mixed thoroughly and separated into 5 subsamples. Subsamples were frozen until they could be dried and blended for nutrient analysis. This methodology for manure sample collection and handling was derived from an analysis of manure handling procedures.

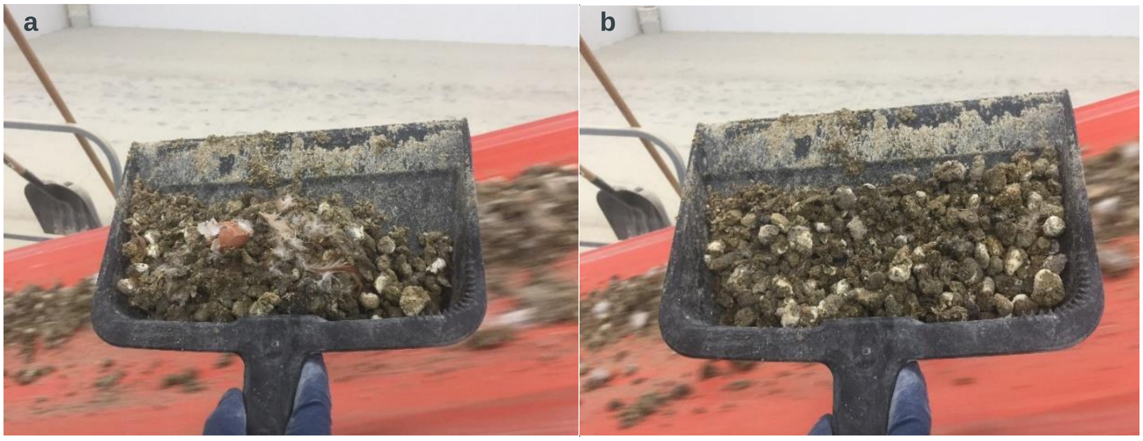

Figure 5. Manure samples collected off the conveyer belt, (a) initial sample with feathers and egg shells, and (b) after they have been removed.

In order to quantify the value of the manure for different scenarios, the manure was tested for TKN by the Kjeldahl digestion method (Table 14). TKN digestion produces slightly lower but consistent results when compared to TN and is the more commonly used analysis method for N. As the manure samples were dried and ground prior to analysis, the N values are given in % weight/dry weight (%w/w) (MC is not part of the value). Five sub-samples were taken for each scenario to capture the variability of nutrient content in the manure.

Statistical analyses were completed using the Analysis of Variance model (ANOVA) in SAS version 9.4 [27]. Differences between moisture content and TKN means for the scenarios were tested using the Duncan's Multiple Range Test. A significance level of $P<0.05$ was used in the study.

The total phosphorus (TP) was measured in all samples for use as a stable marker. This was done to account for any manure volume lost, in addition to moisture since P does not degrade or volatize.

Summer testing took place from June 8 to July 11, 2017 starting at Farm A, and from June 15 to July 18, 2017 at Farm F. The outside temperature for both Farm A and Farm F averaged 9.5°C with a maximum of 36°C and a minimum of 3°C. At Farm A the average outside humidity was 53% and there were 11 days with precipitation. At Farm F, the average outside humidity was 57%, and there were 10 days with precipitation. The changes in outdoor temperature, humidity and effects of barn conditions were summarized and analyzed when comparing the MCs of the manure for different scenarios.

The winter testing took place from January 11 to February 13, 2018 again starting at Farm A, and from January 18 to February 21, 2018 at Farm F. Outside temperatures varied slightly between farms with an outside average temperature at Farm A of -12°C, with a maximum of 6°C and a minimum of -35°C. The average relative humidity during winter testing at Farm A was 78%. At Farm F the average outside temperature was -9°C, with a maximum of 9°C and a minimum of -34°C. The average relative humidity at Farm F was 75% during the testing period.

7.0 In-Barn Testing Results

7.1 In-Barn Ammonia Results

Summer Results

In-barn NH_3 concentrations were measured throughout the summer testing and provided insight regarding the impacts of drying and manure removal frequencies on in-barn NH_3 conditions. The average NH_3 levels at Farm F were consistently higher than Farm A. However, due to a number of factors such as ventilation design and capacity, and total air volume in the barn design, the two barns are not comparable. Therefore, the barns could not be directly compared to each other, but the scenarios within each barn were compared to each other.

The manufacturer supplied NH_3 meters were not consistently accurate and did not respond to barn conditions as fast as the instantaneous measurements collected by the dosi-tubes. The daily dosi-tube measurements were used to correct the permanent meter data to account for some of these inaccuracies. At Farm A, the permanent NH_3 ammonia meter had been installed for over a year prior to the in-barn testing. Therefore, a scaled correction factor was applied to the raw data to develop trends more closely representing the in-barn conditions (Figure 6).

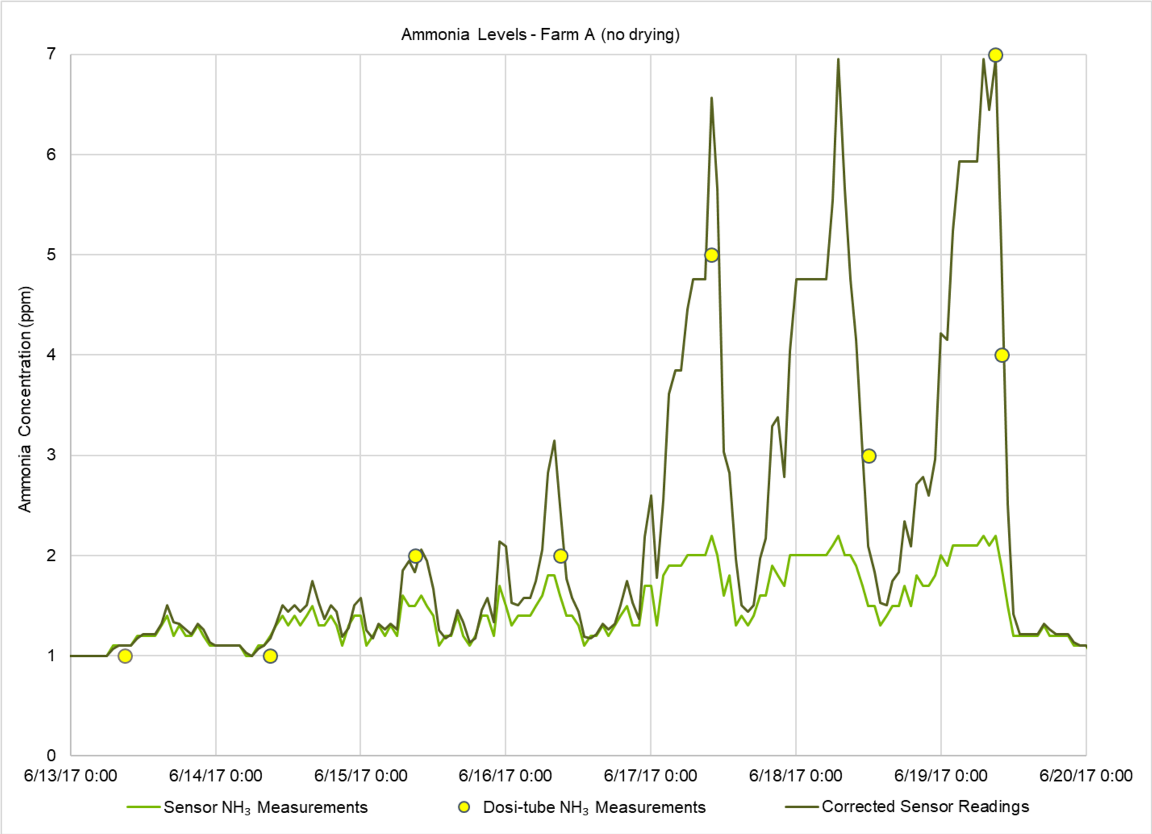

Figure 6. Correction applied to ammonia readings from instantaneous measurements.

At Farm F, the permanent NH_3 meter reached similar maximums measured with the instantaneous dosi-tube measurements therefore a scaled correction factor was not applied; however, it did not respond quickly to changing barn conditions, especially when the NH_3 levels dropped from increased ventilation during the day. As shown in Figure 7, the NH_3 level in the barn dropped drastically with high ventilation rates associated with warmer days. The permanent NH_3 readings generally had a lag time of 2-4 hours to drop to true levels. Measurements with the dosi-tubes indicated that NH_3 levels dropped quickly after the manure was removed from the barn. On July 14th (Figure 7), the NH_3 level dropped from 10 ppm, prior to removal, down to 2 ppm after the manure was removed. However, it took 12 hours for the permanent NH_3 sensor to drop to similar levels. As a result, the average NH_3 levels logged by the permanent sensor did not reflect actual concentrations due to the lag time.

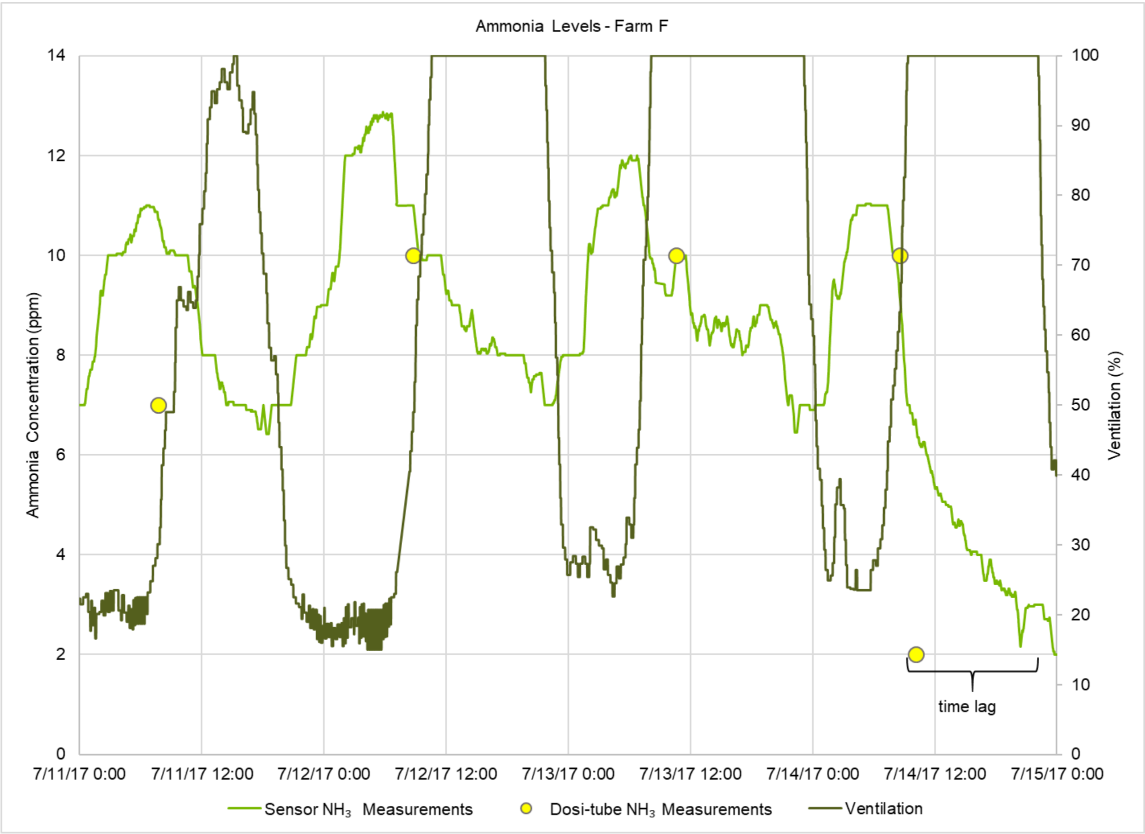

Figure 7. Ammonia levels in Farm F when compared to barn conditions resulting from ventilation rates.

Since the average NH_3 level took some time to drop, the maximum daily NH_3 levels are likely more relevant for comparing the drying scenarios than the average values. The most significant impact on the peak NH_3 levels was the length of time between manure removals, with the 7-day removals having the highest levels (Table 5). After the manure was removed from the barn at the end of each scenario, the NH_3 level was close to 1 ppm at both farms. Without drying, the NH_3 levels reached 7 ppm at Farm A and 14 ppm at Farm F after seven days. With 10 hours of drying, the levels reached 3 ppm at Farm A and 13 ppm at Farm F. Comparatively, with 20 hours of drying per day, the NH_3 levels reached 5 ppm at Farm A and 9 ppm at Farm F. At Farm A, there was no noticeable difference in the NH_3 levels in the barn when comparing 10 hours and 20 hours of daily drying times. However, at Farm F the NH_3 test results were lower with 20 hours of drying as compared to the other scenarios.

Table 5. Summer ammonia concentrations for scenario testing.

Scenario	NH_3 (ppm) Average	NH_3 (ppm) Daily Max	NH_3 (ppm) Average	NH_3 (ppm) Daily Max
	Farm A		Farm F	
Nd1	1.7	2.5	3.5	4.1
Nd3	1.0	1.2	3.4	6.3
Nd7	2.2	7.0	7.5	13.9
10h1	1.1	1.6	2.2	3.4
10h3	1.1	2.6	3.8	9.1
10h7	1.2	3.1	6.7	12.9
20h1	1.4	1.3	3.5	4.0
20h3	1.1	1.3	3.5	5.4
20h7	1.3	4.8	5.3	8.5

Winter Results

At the onset of winter testing it was quickly determined the days of removal would need to be adjusted due to high in-barn NH_3 levels, thus the 7-day removal was reduced to 6 days for winter testing.

At Farm A, as mentioned in the summer results, the permanent NH_3 meter had been installed for over a year prior to the in-barn testing in the summer. When compared to the instantaneous measurements, the permanent meter had lost calibration in the summer testing as it only had approximately 50% of the total range. However, by the time winter testing started the range was down to approximately 13% of the actual values so the meter was of very little value.

Ammonia levels were consistently higher during the winter testing at Farm A as compared to the summer testing, with levels reaching 15 ppm after 6 days with both no drying and 10 hours drying (Table 6). With 20 hours drying, it reached 13 ppm. Also noted, the NH_3 level did not drop as much with daily manure removals, with the lowest value of 5 ppm, as compared to 1 ppm in the summer testing. This is likely due to the lower ventilation rates during the winter, and the manure in the litter may have had more of an impact (in comparison to the summer with full ventilation).

Table 6. Winter ammonia concentrations for scenario testing.

Scenario	NH_3 (ppm) Average	NH_3 (ppm) Daily Max	NH_3 (ppm) Average	NH_3 (ppm) Daily Max
	Farm A		Farm F	
Nd1	5.0	5.0	1.5	1.5
Nd3	6.9	10.0	2.5	5.0
Nd7	9.0	15.0	8.8	25.0
10h1	6.0	7.0	1.3	1.5
10h3	6.6	9.0	2.0	3.0
10h7	8.7	15.0	6.2	10.0
20h1	5.0	5.0	1.0	1.0
20h3	6.4	7.0	2.0	2.0
20h7	8.7	13.0	5.9	10.0

At Farm F, the permanent sensor was installed just prior to the summer in-barn testing, and by the beginning of the winter testing, the total range of values measured by the permanent meter was approximately 55% of the true range. Due to the rapid loss of calibration, or saturation, of these permanent meters, their data was not used in the analysis and they should not be recommended to producers without a calibration plan.

During the winter testing, NH_3 levels reached 25 ppm with no drying after 6 days while it only got to 10 ppm with both 10 hours and 20 hours drying. The high NH_3 levels reached after 6 days of no drying demanded both a reduction in the number of days in the removal scenarios as well as a closer look at the data.

After emptying the barn (Nd6) and downloading the data, an interesting series of events occurred to the peak NH_3 level (25 ppm) (Figure 8). At 7:45pm (on the fifth day of the scenario) the heating turned off (two separate heaters in the barn), however the barn temperature continued to rise, along with the NH_3. In the morning of the sixth day, the barn NH_3 sensor showed a value of 9 ppm, while an instantaneous reading taken with the dosimeter pump and tube recorded a value of 25 ppm (9:00am). The barn ventilation was manually increased from 10% to 40%, for one hour in an attempt to vent the NH_3 when the reduced barn temperature forced reduced ventilation (back to 10%). During that period, the NH_3 level dropped to 13 ppm, but quickly rose to 20 ppm after the ventilation was reduced again. The manure belts were emptied between 10:25am and 10:49am and within 15 minutes NH_3 dropped to 17 ppm, and by 2:00pm, 7 ppm. The increase in barn temperature and NH_3 can likely be associated with the beginning stages of composting, which was caused by the high MC of the manure, the temperature of the barn and the length of time the manure had been sitting on the belts.

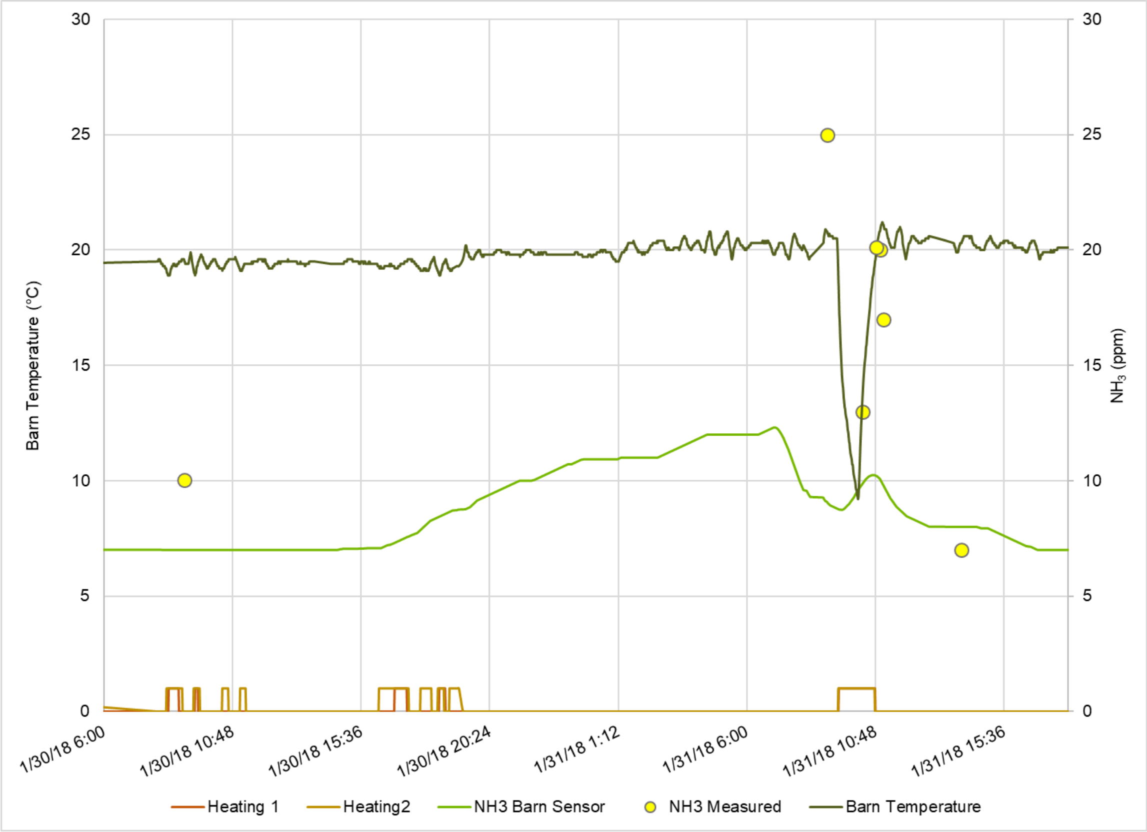

Figure 8. Ammonia levels for the winter Nd6 scenario at Farm F.

To minimize the average NH_3 levels in the barn, increasing the frequency of manure removal is more effective than additional drying. Emptying every three days resulted in lower NH_3 levels in the barns as compared to 20 hours of drying with six or seven day removals for both Farm A and Farm F.

7.2 Manure Moisture Content

Summer Results

The moisture content (MC) was calculated for both farms for each of the scenarios (Figure 9). The drying times, removal frequencies and barn climate conditions all affected the MC.

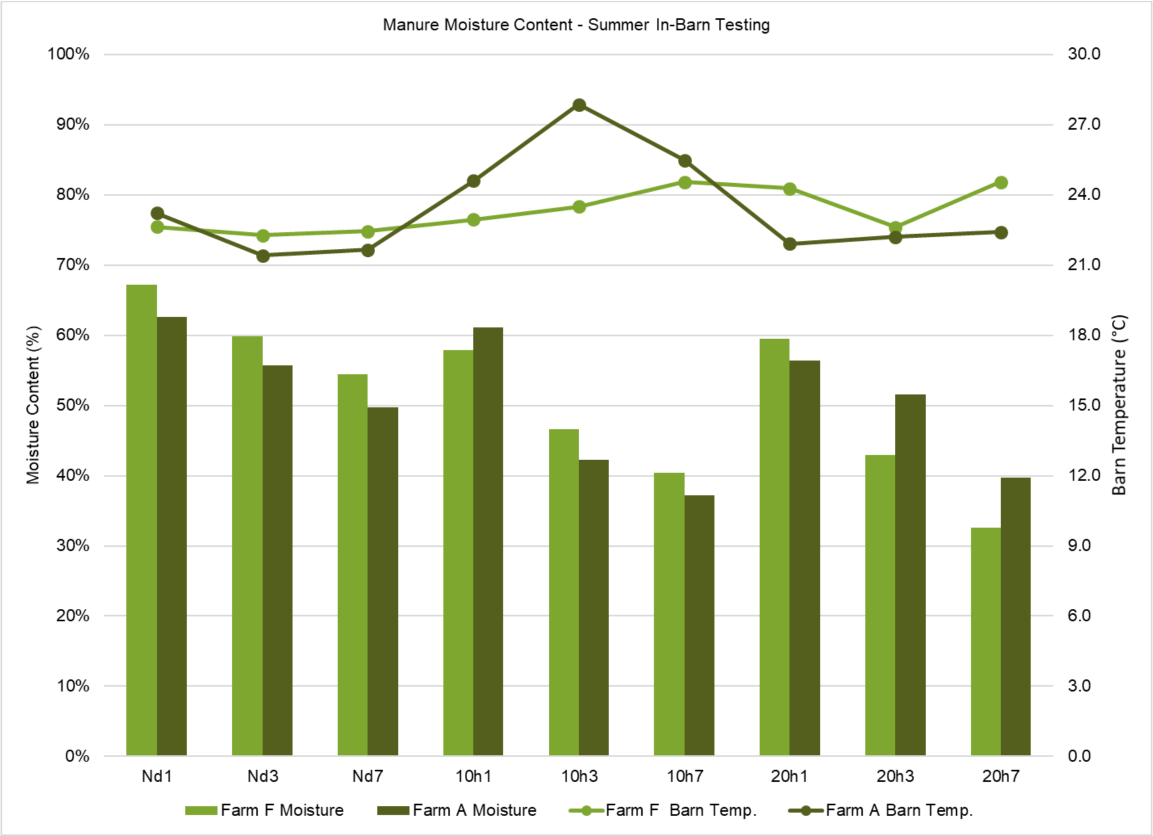

Figure 9. Moisture Contents for manure sampled during summer testing.

The baseline MC was taken as Scenario Nd1 (no drying and manure removed after 24 hours). The MC for this initial scenario was 63% for Farm A and 67% for Farm F. At the conclusion of the summer testing, the scenario was repeated with very similar results; the MC was 63% at Farm A and 68% at Farm F. The overall average MC at Farm A was 52%, with a minimum of 37% and 62% maximum. At Farm F the overall average was 53%, with a minimum of 33% and a maximum of 68%. The average barn temperature for the repeated scenario was 2.6°C lower at Farm A and

1.9°C higher at Farm F than the initial scenario. Understanding that the changes in barn conditions (such as the temperature and humidity) could have affected the MC, it is assumed throughout the duration of the summer testing period there could be at least 1% variance in MC. The overall average barn temperature, for the summer testing, at Farm A was 22°C, with a minimum of 21°C and a maximum of 28°C. At Farm F, the overall average barn temperature was 24°C, with a minimum of 22°C and a maximum of 25°C.

For single day manure removal frequencies, small changes in the MC were observed with the addition of manure drying. With 10 hours of daily drying, the MC dropped by 2% at Farm A and 9% at Farm F (Table 7). At 20 hours of drying, the MC dropped 6% at Farm A and 8% at Farm F.

Table 7. Comparison of moisture content (Δ MC) and barn temperature (Δ Temp) between the summer scenarios.

Scenarios	Δ MC (%)	Δ Temp (°C)	Δ MC (%)	Δ Temp (°C)
	Farm A		Farm F	
Nd1 Repeat vs Nd1	0%	-1.3	1%	0.9
Nd3 vs Nd1	-7%	-1.8	-7%	-0.4
Nd7 vs Nd1	-13%	-1.6	-13%	-0.2
10h1 vs Nd1	-2%	1.4	-9%	0.3
10h3 vs Nd1	-20%	4.6	-21%	0.9
10h7 vs Nd1	-25%	2.3	-27%	1.9
20h1 vs Nd1	-6%	-1.3	-8%	1.6
20h3 vs Nd1	-11%	-1.0	-24%	0.0
20h7 vs Nd1	-23%	-0.8	-35%	1.9

As mentioned previously, statistical analyses were completed using the Analysis of Variance model (ANOVA) in SAS version 9.4 [27]. Differences between moisture content and TKN means for the scenarios were tested using the Duncan's Multiple Range Test. A significance level of

P<0.05 was used in the study. The statistical analysis was done independently for each farm and the MC scenarios were grouped by removal days (1, 3 and 7) (Table 8).

The one-day removal scenarios for both farms were significantly different from each other. At Farm A, the 20 hours drying scenario resulted in the lowest MC of the three. At Farm F, 10 hours drying for the one-day removal scenarios resulted in the lowest MC of 58%.

Table 8. Moisture content statistical comparisons from summer in-barn testing.

Scenarios	**MC (%)**	**MC (%)**
	Farm A	Farm F
Nd1	62.62*a*[z]	67.22*a*
10h1	61.07*b*	57.89*c*
20h1	56.38*c*	59.45*b*
Nd3	55.74*a*	59.84*a*
10h3	42.25*c*	46.56*b*
20h3	51.58*b*	42.92*c*
Nd7	49.71*a*	54.40*a*
10h7	37.16*c*	40.36*b*
20h7	39.74*b*	32.58*c*

[z] Moisture contents per scenario followed by different letters are significantly different at P < 0.05.

For the three-day manure removal frequencies, the drying impact was more substantial. With no drying, changing the removal frequency from one day to three days, the moisture levels dropped by 7% at both Farm A and Farm F. This drop in MC by natural drying on the manure belts over the span of three days, is similar to the amount of drying completed by 20 hours of drying for one day. The MC dropped by 20% at Farm A and 21% at Farm F with 10 hours drying (10h3). Comparatively, at 20 hours of drying, the MC dropped 11% at Farm A and 24% at Farm F (20h3). At Farm A, the hours of drying treatments were significantly different from each other with 10 hours resulting in the lowest MC (Table 10). From these results, it is evident that there were other factors affecting moisture level. At Farm A, the barn temperature was 5.7°C warmer for Scenario

10h3 than it was for 20h3. This indicated the increase in temperature likely accounted for some of the moisture reduction rather than the increase of drying hours at Farm A (comparisons between MC and barn temperature can be seen in Table 8). Comparatively, at Farm F, the barn temperature was 0.9°C higher for scenario 10h3 than it was for 20h3, but the drop in MC was still 4% higher for scenario 20h3 so the extra drying likely had an impact. There was also a significant difference between the drying hours at Farm F.

For seven-day removal frequencies, the biggest drop in MC was observed and there was a significant difference between drying treatments at both farms. With no drying, the moisture levels dropped by 13% at each farm. However, with 10 hours of drying, the moisture content dropped by 25% at Farm A and 27% at Farm F. When the drying was increased to 20 hours per day, the moisture levels dropped by 23% at Farm A and 35% at Farm F. The average barn temperature was 3.1°C higher for Scenario 10h7 than it was for 20h7 at Farm A, which again likely affected the moisture levels. At Farm F, the average barn temperatures were the same for both scenarios so the reduction in MC can likely be attributed to the extra hours of drying. Another interesting result was only at the seven days removal did the MC at both farms drop below the 40% MC threshold, where literature [19] states that NH_3 emissions are reduced. At Farm A this occurred for both the 10 and 20 hour scenarios, while at Farm F it only occurred for the 20 hours drying scenario (Table 9).

Another consideration in analyzing temperature and humidity impacts on drying capacity is the water carrying capacity of air within the barn and drying system. As air heats up, it has the capacity to hold more moisture and dry more effectively. The relative humidity (RH) of air is the percentage of moisture in the air at a specific temperature. Therefore, if no moisture is added to or lost from the air, and the temperature drops, the RH will increase. For drying analysis, the remaining capacity of the air to hold moisture was calculated by multiplying the RH by the total capacity at each specific temperature.

$$MHC(T) = (1 - RH) * 0.002166 \frac{610.78 * e^{17.2694 * \frac{T}{T+238.3}}}{T + 273.16} * 1000$$

where,

$MHC(T) = \text{Moisture Holding Capacity at given temperature} \left(\frac{\text{kg}}{1000\ \text{m}^3}\right)$

$T = \text{Temperature (°C)}$

It is expected the higher the MHC of air, the better the manure will be dried. Therefore, the MHC was calculated for the instantaneous readings of temperature and humidity for both the barn air and the drying air (Table 9). The scenarios with the largest barn outliers are scenarios 10h3 and 10h7 for Farm A. As noted earlier, the MC was 9% lower for 10h3 than 20h3 and 3% lower for 10h7 than 20h7 for Farm A. This difference in MC does not align with the extra drying time, but is likely influenced by the extra MHC in the barn air for the 10 hour drying scenarios. The MHC of the drying air was actually lower than average for those same scenarios. This is because the dryer was used overnight at Farm A, so the air used for drying in these scenarios was cooler than average daytime air and therefore had a lower MHC.

Table 9. Average moisture content holding capacity for each scenario for summer testing.

Scenarios	**MHC Barn (kg/1000 m^3)**	**MHC Dryer (kg/1000 m^3)**	**MHC Barn (kg/1000 m^3)**	**MHC Dryer (kg/1000 m^3)**
	Farm A		Farm F	
Nd1	12.0	-	9.6	-
Nd3	11.1	-	11.7	-
Nd7	9.7	-	11.4	-
10h1	11.0	4.9	13.5	11.5
10h3	18.0	9.6	12.1	10.2
10h7	14.4	8.3	11.7	9.9
20h1	10.9	10.3	11.9	13.8
20h3	10.7	10.0	11.4	11.2
20h7	11.4	10.6	12.4	14.3
Nd1 Repeat	*8.4*	-	13.8	-

Of the two barns, the ventilation, heating and cooling at Farm F could have more impact on the manure drying as the inlets, heating tubes and misting lines were all close to the top tiers of cages and belts. In order to determine if these factors and the nature of the tiered cage system in itself at Farm F affected natural drying in the barn, manure samples were taken from different belts. The samples were taken from the bottom, middle and top row for scenario Nd7. This scenario was chosen as the only impact was natural drying, and the 7-day removal period gave a better sample size than the smaller removal periods. The average MC was 54% after manure was collected from all 5 rows. However, the top row had a MC of 64%, the middle row was 49% and the bottom row was 51%. This showed MC of the top row was much higher. These differences may have been due to the circulation fans placed in-between the rows and or the misting system located directly above the top tiers. Winter testing will show how much natural drying changes the MC when neither circulation fans nor misting systems are operating.

Winter Results

The baseline MC data for the winter scenario Nd1 was 64% at Farm A and 70% at Farm F, both slightly higher than the Nd1 scenarios in the summer of 63% and 67% respectively. As in the summer, the Nd1 scenarios were repeated in each barn to test for variance over the testing period. The Nd1 repeat MC for Farm A was 63% and 73% for Farm F, both very similar to the original samples. Barn temperature at both farms was very stable during the winter testing, with a minimum of 21.5°C and a maximum of 21.8°C, with an average of 21.6°C at Farm A. At Farm F, the minimum temperature was 18.5°C and the maximum 19.5°C with an average of 19°C (Figure 10). In contrast to the summer testing, the MC did not drop below 40% for any of the testing scenarios.

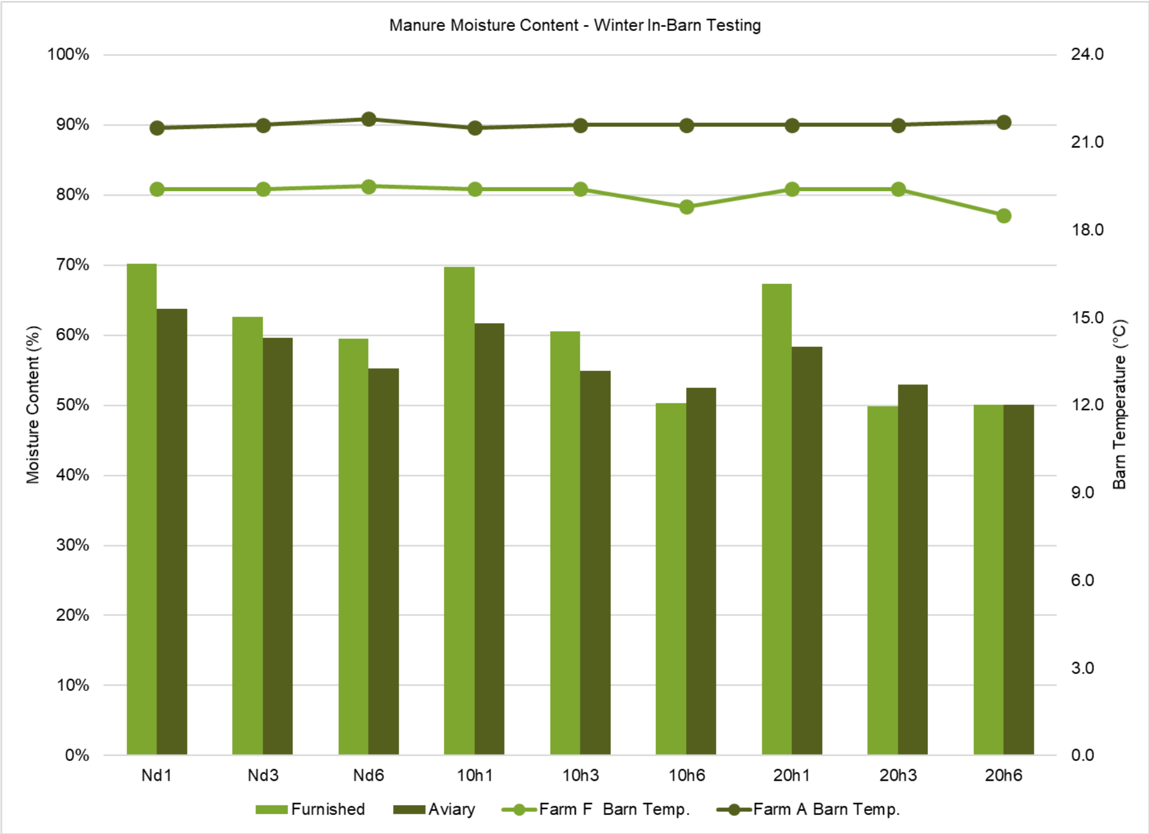

Figure 10. Moisture contents and barn temperatures collected during the winter in-barn testing.

Statistical analysis of the drying treatments for each of the removal day scenarios were significantly different at both farms, with 20 hours of drying resulting in the lowest MC (Table 10).

Table 10. Moisture content statistical comparisons from winter in-barn testing

Scenarios	MC (%)	MC (%)
	Farm A	Farm F
Nd1	63.80*a* [z]	70.15*a*
10h1	61.67*b*	69.83*a*
20h1	58.32*c*	67.29*b*
Nd3	59.59*a*	62.63*a*
10h3	54.87*b*	60.47*b*
20h3	52.99*c*	49.80*c*
Nd7	55.24*a*	59.55*a*
10h7	52.44*b*	50.27*b*
20h7	50.07*c*	46.92*c*

[z] Moisture contents per scenario followed by different letters are significantly different at $P < 0.05$.

For the one-day manure removal frequencies, similar to summer results, there were small changes in the MC observed with the addition of drying. At Farm A, a 2% reduction in MC was the result of 10 hours (10h1) of drying and 20 hours (20h1) resulted in a reduction of 5% (Table 11). At Farm F, 10 hours of drying had no effect on MC and 20 hours resulted in a 3% reduction.

Table 11. Comparison of change in moisture content (Δ MC) and barn temperature (Δ Temp) between the winter scenarios at both farms.

Scenarios	Δ MC (%)	Δ Temp (°C)	Δ MC (%)	Δ Temp (°C)
	Farm A		Farm F	
Nd1 Repeat vs Nd1	0%	0.1	3%	-0.1
Nd3 vs Nd1	-4%	0.1	-8%	0.0
Nd7 vs Nd1	-9%	0.2	-11%	0.1
10h1 vs Nd1	-2%	-0.1	0%	0.0
10h3 vs Nd1	-9%	0.0	-10%	0.1
10h7 vs Nd1	-11%	0.0	-20%	-0.6
20h1 vs Nd1	-5%	0.1	-3%	0.0
20h3 vs Nd1	-11%	0.1	-27%	0.0
20h7 vs Nd1	-14%	0.1	-20%	-0.8

For the three-day manure removal frequencies, more substantial reductions were observed with drying when compared to the no drying one-day removal scenario. As the barn temperatures were very stable during the winter testing, the reductions in MC can clearly be linked to the addition of drying. With no drying and increasing the removal frequency to three days, the moisture dropped by 4% at Farm A and 8% at Farm F (Table 11). For 10 hours (10h3) of drying at Farm A, MC was reduced by 9% and 20 hours (20h3) resulted in an 11% reduction. At Farm F the difference with additional drying was more substantial with a 10% reduction after 10 hours (10h3) and a 27% reduction after 20 hours (20h3).

When comparing the MC (Table 11) reductions at Farm A, removing manure after three days with no drying (Nd3) was comparable to removal after one day with 10 hours (10h1) drying and removal after one day at 20 (20h1) hours of drying. At Farm F, removing manure after three days with no drying (Nd3) resulted in more MC reduction than both removals after one day with 10 hours (10h1) drying and removal after one day at 20 hours (20h1) of drying.

For the 6-day removal frequencies at Farm A, like the summer results, without forced air-drying there is still a reduction in MC. The Nd6 scenario resulted in a MC reduction of 9%, as compared to an 11% reduction for the 10h6 scenario and a 14% reduction for the 20h6 scenario. At Farm F, the Nd6 scenario had an 11% reduction in MC, a 20% reduction after the 10h6 scenario and a 20% reduction after the 20h6 scenario. In this comparison at Farm F, while the 10h6 and 20h6 scenarios resulted in the same MC reduction, the humidity during the 20h6 scenario was almost 8% (at 58.8% humidity) higher than in the 10h6 scenario (51.1% humidity).

Although the in-barn temperature was more consistent for the winter testing, the impact of the barn humidity was evident in the Moisture Holding Capacity (MHC) of the air, which affected the amount of drying for the different scenarios (Table 12). On average, the MHC was lower in the winter than in the summer testing. At Farm F, the 20h7 scenario had the lowest MHC for both the Barn air and the Dryer air. This could explain why there was similar MC reduction in the 10h6 and 20h6 scenarios. At Farm A, the MHC was more consistent, but the MHC of the air going through the Dryer was lower for some of the scenarios due to colder duct temperatures during those scenarios.

Table 12. Moisture holding capacity of barn and drying air for winter testing.

Scenarios	MHC Barn (kg/1000 m³)	MHC Dryer (kg/1000 m³)	MHC Barn (kg/1000 m³)	MHC Dryer (kg/1000 m³)
	Farm A		Farm F	
Nd1	10.3	-	9.8	-
Nd3	10.3	-	9.4	-
Nd7	10.7	-	9.0	-
10h1	9.6	7.2	8.6	9.2
10h3	10.0	7.7	7.8	8.3
10h7	10.1	7.9	7.8	8.7
20h1	11.5	10.0	8.7	9.2
20h3	10.2	8.7	9.1	9.1
20h7	10.2	9.1	6.5	6.9
Nd1 Repeat	*11.5*	-	*10.0*	

7.3 Manure Nutrient Content

Summer Results

The average N levels across all scenarios were 5.95 %w/w for Farm A and 4.86 %w/w for Farm F. The N levels at Farm A ranged from 5.62 %w/w for scenario 10h7 to 6.31 %w/w for Scenario 20h3 (Table 13). Comparatively at Farm F, the N levels ranged from 3.94 %w/w for scenario Nd7 to 5.54 %w/w for scenario 20h3.

Table 13. Nutrient content statistical comparisons and subsample variation from summer in-barn testing.

Scenario	TKN (%w/w)[z]	Subsample Variation (%)	TKN (%w/w)	Subsample Variation (%
	Farm A		Farm F	
Nd1	5.94*a*[y]	7%	4.81*b*	8%
10h1	6.00*a*	6%	5.52*a*	4%
20h1	6.07*a*	11%	4.37*c*	6%
Nd3	5.81*b*	9%	4.19*c*	4%
10h3	5.62*b*	6%	5.12*b*	6%
20h3	6.31*a*	3%	5.54*a*	7%
Nd7	6.07*a*	8%	3.94*c*	14%
10h7	5.62*b*	3%	4.86*b*	8%
20h7	6.13*a*	3%	5.43*a*	6%

[z] TKN is expressed as a percentage of the dried weight of the manure sample (% weight/dry weight).

[y] Nitrogen content per scenario followed by different letters are significantly different at $P < 0.05$.

At Farm A, the variation within the subsamples from the same scenario varied from 3-11%. For the one-day removal scenarios, the 20 hour (20h1) drying treatment had the highest TKN content at 6.07 %w/w, however there was no significant differences between the drying treatments (Table 13). N content for the three-day removal scenarios was highest for the 20 hours (20h3) drying, which was significantly different than the no drying (Nd3) and 10 hours (10h3) drying treatments. There was no significant difference between the no drying (Nd3) and 10 hours (10h3) drying treatments. For the seven-day removal scenarios, no drying (Nd7) and 20 hours (20h7) drying had significantly more TKN content in the manure compared to 10 hours (10h7) drying, however there was no significant difference between the treatments (Figure 11).

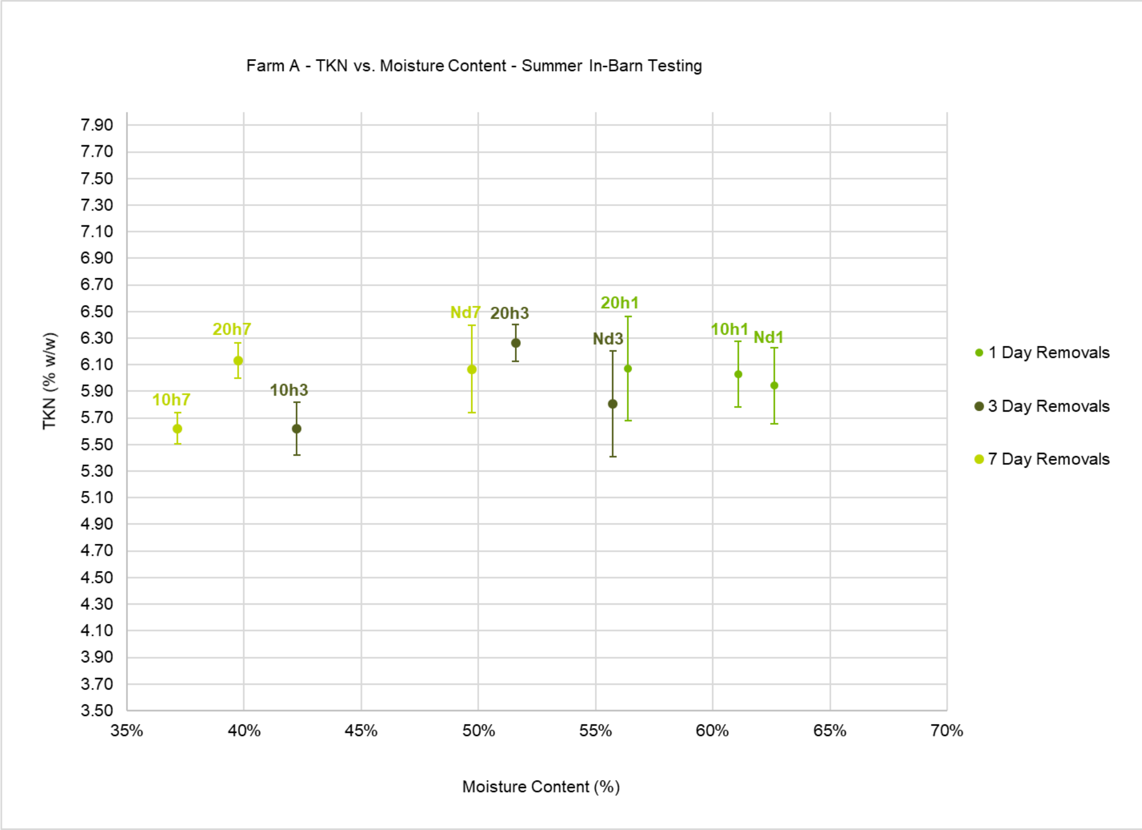

Figure 11. Comparison between nitrogen and moisture content for scenarios at Farm A from the summer testing.

At Farm F, the differences of TKN between the scenarios was larger and some trends could be observed (Table 13). When comparing the 1-day removal scenarios, the TKN went from 4.81 % w/w with no drying (Nd1), 5.52 % w/w with 10 hours (10h1) drying, and 4.37 % w/w with 20 hours (20h1) drying. Although the treatments were all significantly different, no trend was observed in the manure N levels. This could be an indication of the day-to-day variability in the poultry manure.

For the 3-day removal periods, the N level went from 4.19 % w/w for no drying (Nd3) (60% MC) to 5.12 % w/w for 10 hours (10h3) drying (47% MC) and 5.54 % w/w for 20 hours (20h3) drying (43% MC). Each treatment was significantly different and is theoretically what is expected with the use of a manure dryer, in that N content would be higher in dried manure as the losses of NH_3 due to volatilization would be reduced thus more N retained in the manure.

The 7-day removal period gives a larger manure sample size (averages seven days of variability). For these scenarios, the N level went from 3.94 % w/w for no drying (Nd7) (54% MC) to 4.86 %

w/w for 10 hours (10h7) drying (40 % MC) and 5.43 % w/w for 20 hours (20h7) drying (33% MC), each significantly higher than the previous (Table 13). Therefore, if the daily removal scenario is disregarded due to small sample size, the 20 hour drying scenarios had 28% higher TKN values for the three-day removal and 30% higher for the seven-day removal scenarios when compared to the no drying scenarios (Figure 12).

Figure 12. Comparison between nitrogen levels and moisture content for Farm F summer testing.

Total phosphorus (TP) was compared to days of manure removal to see if there were measurable losses of dry manure volume. As shown in Figure 13, the TP after seven days ranged from being 23% lower (20 hours drying – Farm F) to 16% higher (no drying – Farm A) than the levels after 1-day removal. The average change was a 1% drop from the 1-day samples to the 7-day samples. Since there was no consistent increase in the levels of P in the manure, the losses of mass due to volatilization and degradation appear to be negligible and the comparison of N with respect to dry matter is justified.

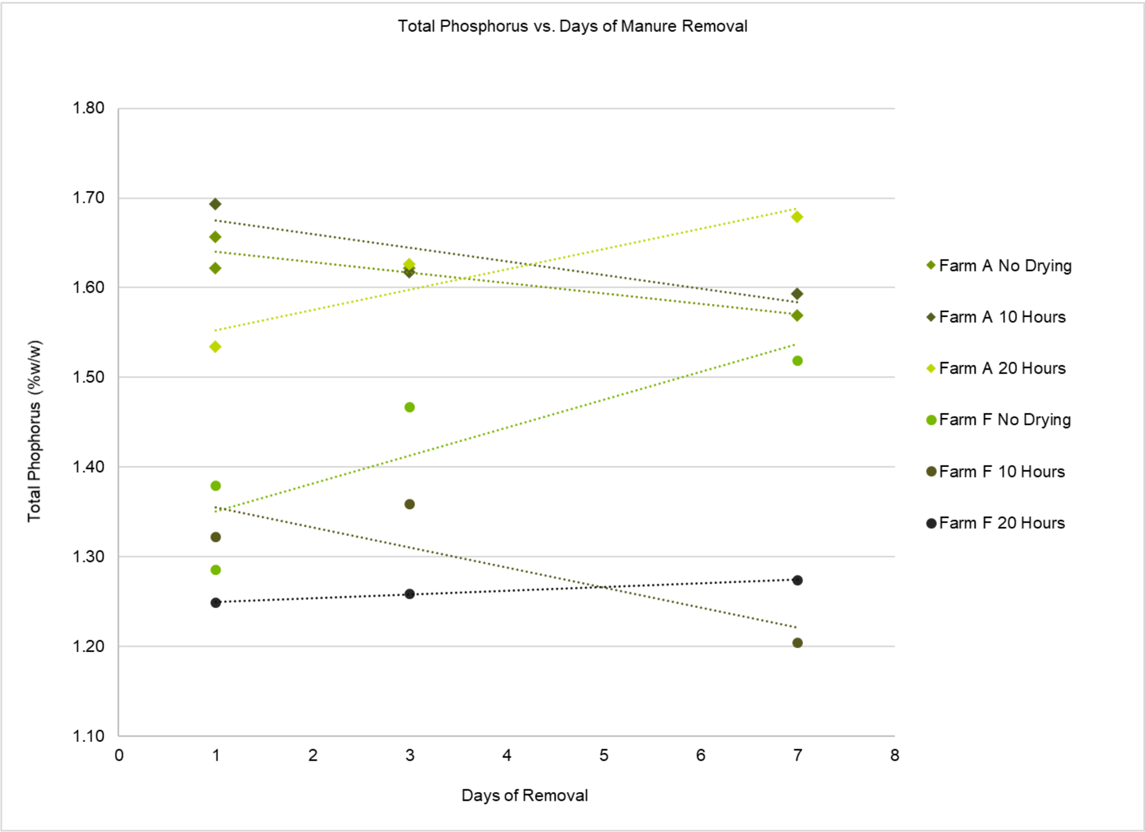

Figure 13. Comparison between total phosphorus and the length of time manure was in the barn.

Winter Results

For the winter testing, Farm A N levels ranged from 4.59 % w/w to 6.22 % w/w (Table 14) with an average of 5.43 % w/w TKN. At Farm F, the N levels ranged from 6.28 % w/w to 7.18 % w/w with an average of 6.70 % w/w TKN. It is interesting to note the TKN levels at Farm F were lower than Farm A in the summer, but were higher in the winter. This difference was likely caused by changes regarding bird age and feed rations.

For the one-day removals at both farms, the highest TKN occurred in the no drying scenarios with 5.88 % w/w at Farm A and 7.18 %w/w at Farm F. At Farm A, the no drying (Nd1) and 10 hour (10h1) drying scenarios were not significantly different from each other but were significantly higher than the 20 hour (20h1) drying treatment. At Farm F, the no drying (Nd1) treatment was significantly higher than both the 10 (10h1) and 20 hours (20h1) of drying (Table 14).

The highest TKN results for the three-day removals for both farms was again found in the no drying treatments. At Farm A, the no drying (Nd3) and 20 hours (20h3) of drying were not significantly different, but were significantly higher than the 10 hour (10h3) drying treatment. At Farm F the treatments, though not significantly different, resulted in higher TKN content in the no drying treatment.

For the seven-day removal scenarios, the results were very similar to the three-day removal scenarios. At Farm A, 20 hours (20h7) of drying resulted in the highest TKN content followed by no drying (Nd7) with no significant difference between the two. Lowest TKN content resulted from 10 hours (10h7) of drying. At Farm F, the treatments yielded no significant difference (Table 14).

Table 14. Nutrient content statistical comparison and subsample variation from winter in-barn testing.

Scenario	TKN (%w/w)[z]	Subsample Variation (%)	TKN (%w/w)	Subsample Variation (%
	Farm A		Farm F	
Nd1	5.88*a* [y]	9%	7.18*a*	3%
10h1	5.85*a*	18%	6.81*b*	3%
20h1	5.01*b*	12%	6.84*b*	4%
Nd3	6.22*a*	15%	6.74*a*	10%
10h3	5.15*b*	8%	6.28*a*	6%
20h3	6.15*a*	5%	6.63*a*	4%
Nd7	5.23*a*	5%	6.84*a*	12%
10h7	4.59*b*	10%	6.64*a*	6%
20h7	5.60*a*	8%	6.35*a*	5%

[z] TKN is expressed as a percentage of the dried weight of the manure sample (% weight/dry weight).

[y] Nitrogen levels per scenario followed by different letters are significantly different at $P < 0.05$.

As with summer testing, manure phosphorus levels were measured for the winter testing. The average level of phosphorus was 1.78% at Farm A and 1.43% at Farm F. There were no trends of increased phosphorus levels with longer manure removal periods which indicates there was not major degradation of the manure in the 6-day time frame. However, at Farm F the first two scenarios that were completed (Nd1 and Nd3) had significantly lower phosphorus levels. This could indicate a change in the manure, which could also cause uncertainty for the N levels in the manure as well. This change could be as a result of diet change, bird age, or sampling error.

Nutrient results show no statistically significant trends indicating retained N in the manure with increased drying. However, from the measured NH_3 levels in the barn, it can be inferred less NH_3 is lost with increased drying, which should lead to some level of retained N unless it is lost in another form other than NH_3. In order to try to quantify the retained N in the manure, a more structured study would be necessary to compare the scenarios simultaneously to potentially remove some of the variability introduced by the scale of commercial farms, different bird ages, different climate conditions and other variables that could change over a period of time.

7.4 Energy and Power Usage

Energy and power usage was logged for the dryer and the manure belts at both farms. The 7.5 hp motor in the drying fan at Farm F used 4.5 kilowatt (kW) while the 4 hp motor at Farm A used an average of 1.75 kW. The energy the manure belts used while removing the manure varied from 0.81 - 1.12 kilowatt hour (kWh) per removal at Farm F and 1.28 - 1.87 kWh per removal at Farm A (Figure 14). The variation in energy usage of the manure belts depended on the weight of the manure on the belts which varied with the days between removal and the manure MC. The effect of the manure weight is evident as usage decreased as the belts were emptied.

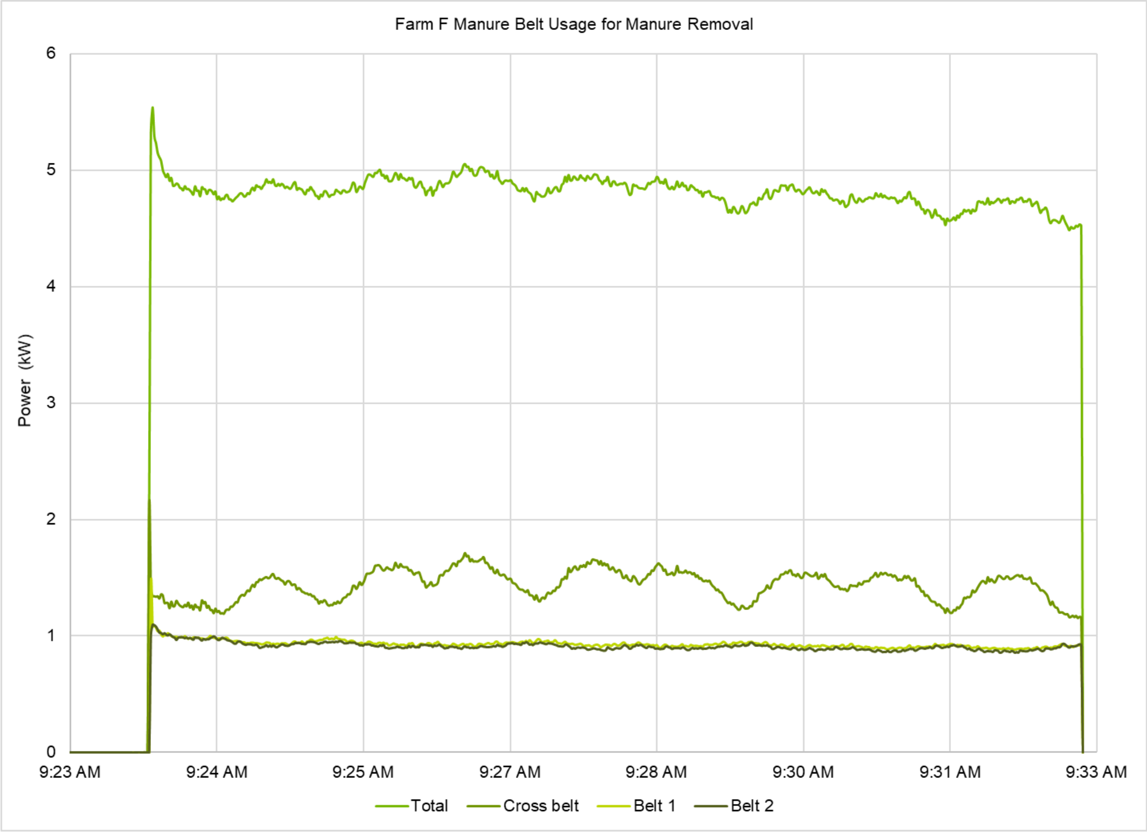

Figure 14. Example of energy consumption of manure belts while emptying at Farm F. The total energy was calculated for all four rows of belts as only two of the rows were monitored.

From the energy consumption used for the drying fan and the manure removal, the total energy consumption was calculated to evaluate the changes between scenarios. The energy consumption during manure removal is negligible, with the manure belt usage resulting in only 7% and 2% of the total energy used by the dryer at Farm A and F respectively (Table 15).

Table 15. Yearly energy consumption calculated for the tested scenarios.

Scenario	Belts (kWh)	Dryer (kWh)	Total Energy (kWh)	Belts (kWh)	Dryer (kWh)	Total Energy (kWh)
	Farm A			Farm F		
Nd1	502	0	502	300	0	300
Nd3	188	0	188	115	0	115
Nd7	97	0	97	59	0	59
10h1	469	6380	6849	291	16515	16806
10h3	162	6380	6542	104	16515	16619
10h7	81	6380	6461	54	16515	16569
20h1	487	12,760	13,247	305	33,030	33,335
20h3	175	12,760	12,935	107	33,030	33,137
20h7	87	12,760	12,847	51	33,030	33,081

During the winter testing the average power consumption of the dryer was 1.87 kW at Farm A and 4.31 kW at Farm F. The consumption was slightly higher during the winter testing at Farm A and lower at Farm F. A number of factors could make small changes to the energy consumptions such as air temperature, humidity, dryer maintenance and cleanliness. While the energy consumption of the dryers is considerably higher than the belts, the difference in the annual operating costs between drying and no drying is negligible (Table 16 and 17).

Table 16. Annual energy consumption and cost calculated for Farm A.

Scenario	Usage (GJ)	Cost ($2.86/GJ)	Usage (kWh)	Cost ($0.05/kWh)	Total Cost
	Natural Gas		Electricity		
Nd1	891	$ 2,548.26	15719	$ 848.83	$ 3,397.09
Nd3	1113	$ 3,183.18	15822	$ 854.39	$ 4,037.57
Nd7	1206	$ 3,449.16	15864	$ 856.66	$ 4,305.82
10h1	920	$ 2,631.20	15738	$ 849.85	$ 3,481.05
10h3	1174	$ 3,357.64	15863	$ 856.60	$ 4,214.24
10h7	1296	$ 3,706.56	15935	$ 860.49	$ 4,567.05
20h1	997	$ 2,851.42	15791	$ 852.71	$ 3,704.13
20h3	1271	$ 3,635.06	15949	$ 861.25	$ 4,496.31
20h7	1329	$ 3,800.94	15971	$ 862.43	$ 4,663.37

Table 17. Annual energy consumption and cost calculated for the scenarios for Farm F.

Scenario	Usage (GJ)	Cost ($2.86/GJ)	Usage (kWh)	Cost ($0.05/kWh)	Total Cost
	Natural Gas		Electricity		
Nd1	498	$ 1,424.28	20005	$ 1,080.27	$ 2,504.55
Nd3	759	$ 2,170.74	20005	$ 1,080.27	$ 3,251.01
Nd7	839	$ 2,399.54	20005	$ 1,080.27	$ 3,479.81
10h1	508	$ 1,452.88	20015	$ 1,080.81	$ 2,533.69
10h3	801	$ 2,290.86	20037	$ 1,082.00	$ 3,372.86
10h7	948	$ 2,711.28	20150	$ 1,088.10	$ 3,799.38
20h1	585	$ 1,673.10	20093	$ 1,085.02	$ 2,758.12
20h3	933	$ 2,668.38	20250	$ 1,093.50	$ 3,761.88
20h7	971	$ 2,777.06	20215	$ 1,091.61	$ 3,868.67

7.5 Dust

Since dust is a concern for farmers, in-barn dust levels were measured throughout the summer testing. From the recordings, noticeable trends were observed for both barns. The dust levels were measured in particle counts greater than 0.5 microns (small particles) and everything greater than 2.5 microns (large particles).

The dust meters showed a noteworthy difference between the aviary free-range system and furnished caged system. At Farm A, the average dust levels, when the lights where on (from 7:30 AM – 11:30 PM), was 3.6 million particles per cubic foot (mppcf) (0.36 mg/m^3). When the lights were off, the dust levels dropped to 0.3 mppcf (0.03 mg/m^3). For comparison, the dust levels at Farm F with lights on was 0.6 mppcf (0.06 mg/m^3) and 0.1 mppcf (0.01 mg/m^3) with lights off. This difference is likely due to the extra bird activity and the dry floor litter in the aviary system.

Both farms showed repeatable trends, which suggests that dust levels without drying (green line) were typically higher than levels when drying was turned on, particularly with 20 hours of drying (red line). At Farm A, the dust levels rapidly increased as the lights turned on in the morning and then generally increased again at approximately 12:00 PM as the hens finished laying their eggs and congregated in the litter areas (Figure 15). As shown in Figure 15 dust levels were actually the lowest during the 20 hour drying scenarios so some other factors such as ventilation must impact the dust levels. As well, there was no difference in the dust levels corresponding to the times of day the dryers turned on or off. Farm F showed similar trends as Farm A with an increase in dust levels when the lights turned on even though there was no litter for the hens to dig around in (Figure 16). Farm F also did not show higher dust levels for the scenarios with drying, and there was no evidence of increased dust levels over time that may have been caused by accumulated drying in the 7-day removal scenarios.

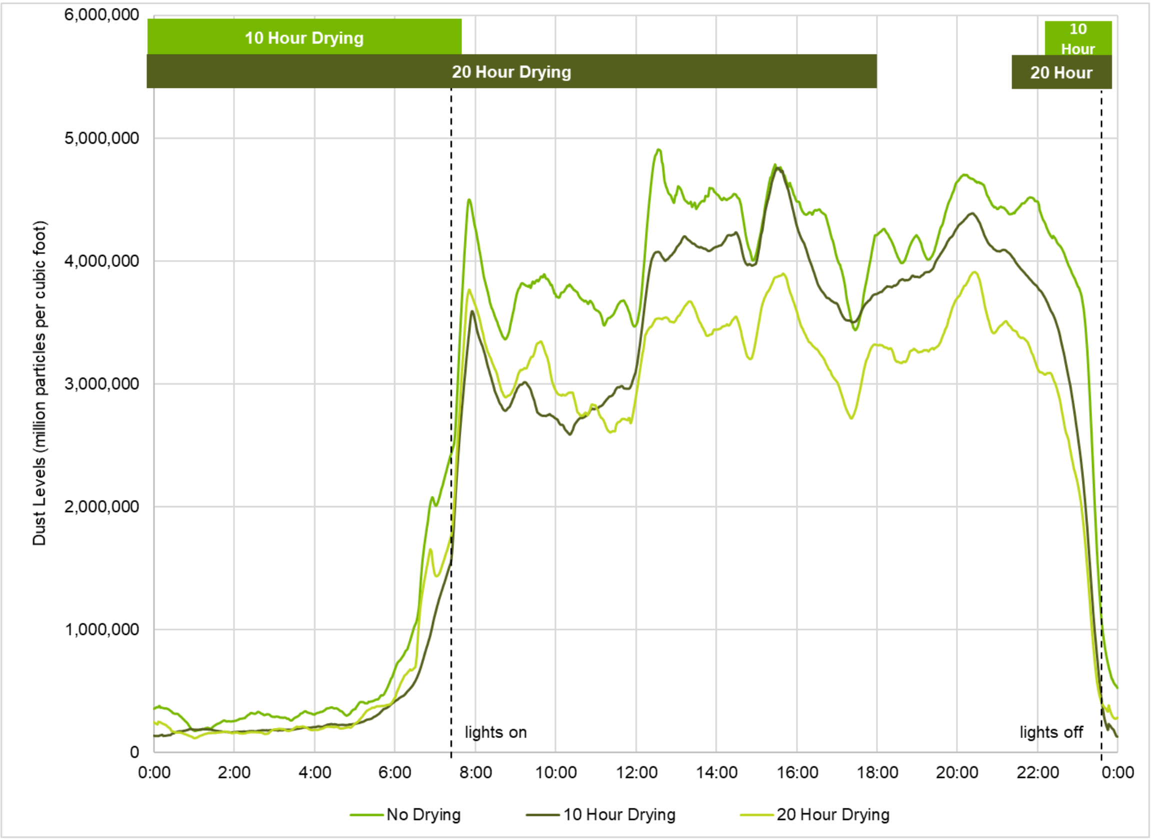

Figure 15. Dust levels at Farm A averaged over drying scenarios. The dark green (20 hours of drying) and the light green (10 hours drying) bars on the top of the graph show the time of day the

dryer was operating to reference the dust levels. Dust measurement reflects particles greater than 0.5 microns in size.

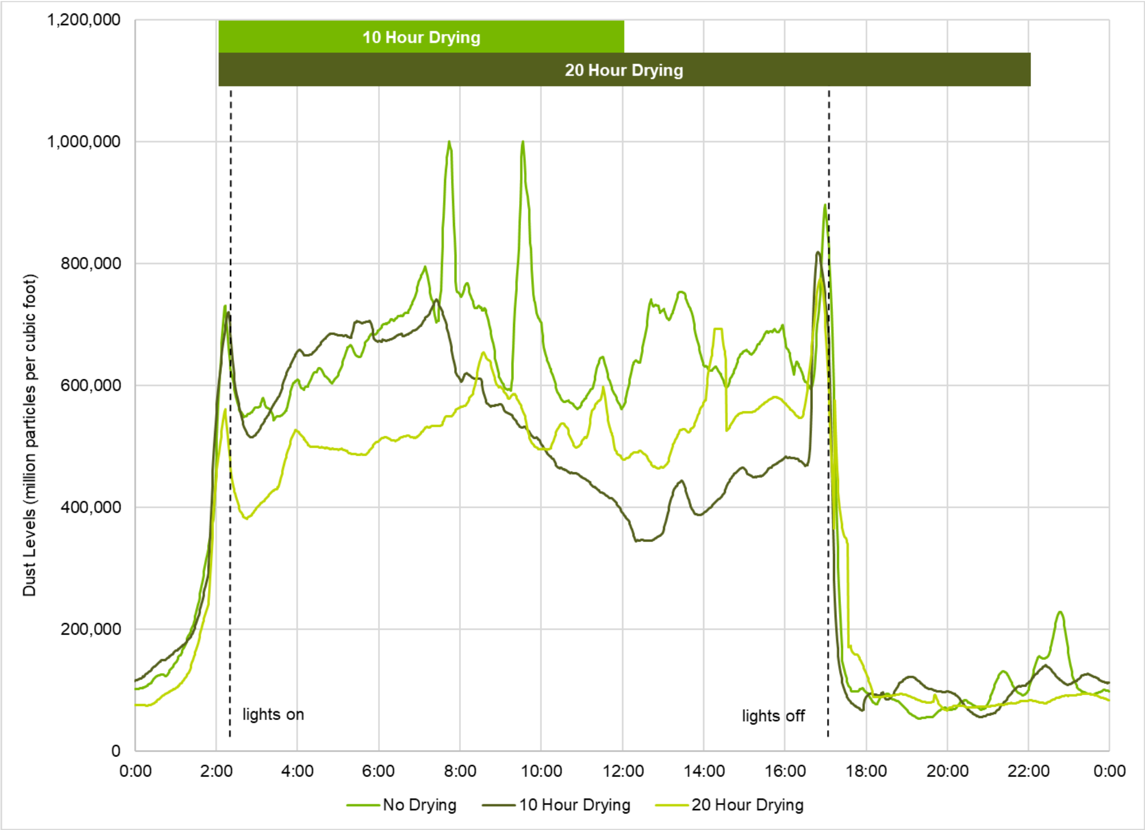

Figure 16. Dust levels at Farm F averaged over drying scenarios. The red (20 hours drying) and the blue (10 hours drying) bars on the top of the graph show the time the dryer was operating to reference with the dust levels. Dust measurement reflects particles greater than 0.5 microns in size.

The winter testing provided similar trends to the summer testing. As with the summer testing, the scenarios with drying did not show any higher dust measurements than with no drying at either Farm A or Farm F. However, the average dust levels in the winter testing were higher than in summer. At Farm A, the dust level was 4.3 mppcf (0.43 mg/m^3) with the barn lights on and 0.6 mppcf (0.06 mg/m^3) with lights off during the winter testing which was on average 20% higher than summer testing. By comparison, at Farm F, the dust level was 1.7 mppcf (0.17 mg/m^3) with the barn lights on and 0.4 mppcf (0.04 mg/m^3) with lights off during the winter testing which is 2.8 times higher than summer testing. Farm F still had much lower average dust levels, but the dust levels were more significant in winter testing. The most likely reason to explain the increase in average dust levels is the reduction in ventilation when comparing winter with summer testing.

A literature review found that dust levels, similar to this study, have been recorded for both furnished housing systems and aviary systems in the US. A conversion factor [28], for converting mppcf to mg/m3, was applied to allow for comparison of results. Table 18 shows a comparison of dust levels from Farm A and Farm F to values from two studies conducted in the US.

Table 18. Comparison of in-barn dust levels from Farm A (aviary) and Farm F (furnished) to two US studies.

Author	Furnished Housing	Floor Housing	Aviary
		mg/m^3	
Summer	0.06	-	0.36
Winter	0.17	-	0.43
Zhao et al. [29]	0.06	-	0.41
Bouquin et al. [30]	0.13	0.37	1.19

7.6 Other Considerations

From the in-barn NH_3 levels, it is evident that more frequent manure removal would improve air quality. As the energy consumption for the removal belts is considerably less than the drying fans, energy could be saved by more frequent manure removal. However, the labour requirements for farm employees would increase. At Farm A, manure removal times varied from 26 minutes for 1 or 3-day removals (one trip from barn to storage pile) to 33 minutes for 7-day removal (2 trips from barn to storage pile). When adding the prep and cleanup time, approximately 45 minutes of labour would be needed for each manure removal. Since the barn at Farm F was not as long, removal was quicker with removal times ranging from 11 minutes for 1 and 3-day manure removal periods and 29 minutes for 7-day removals (due to the need for 2 loads). With the prep and cleanup time, the total time for a year of daily removal for both farms is shown in Table 19.

In addition to more time commitments with increasing removal frequency, there is also increased machinery usage and cost for bringing the manure to the storage. At Farm A, it took approximately 5 minutes per load while at Farm F it took approximately 12.5 minutes per load. At both farms, 1-day and 3-day removals took one load while seven day removals took two loads.

Table 19. Annual labour and equipment requirements calculated for the tested scenarios.

Removal Frequency	Labour Hours	Hauling Equipment Hours	Labour Hours	Hauling Equipment Hours
	Farm A		Farm F	
1- day	274	30	213	76
3 - day	91	10	71	25
7- day	44	9	46	22

Increased drying also led to decreased manure weights due to the removal of moisture from the manure. At Farm F, the total manure was weighed for the scenarios with seven-day removal periods. With no drying, the manure weighed 4970 kg (0.42kg/bird), for 10 hours drying it was 4030 kg (0.34kg/bird) and for 20 hours drying it was 3730 kg (0.31kg/bird). There was a substantial weight reduction between the no drying and 10 hours drying scenarios of 940 kg, and a 300 kg reduction difference between 10 hours and 20 hours of manure drying. The decreased weight of the manure could save in transportation costs if it needed to be hauled long distances. During the winter testing, the manure weighed 5070 kg (0.42kg/bird) with no drying and 4100 kg (0.34 kg/bird) with 20 hours drying. The total weight per bird was similar in the summer and winter testing, but the dry matter weight of manure was 15% lower in the winter testing, likely due to the younger bird age. Manure weights at Farm A were not collected due to lack of scale access.

8.0 Economic Analysis

Relevant data was analyzed to determine if manure dryer belts provide a positive return on the investment. For cost variables, average costs were used as shown in Table 20.

Table 20. Cost variables used for economic analysis.

Variable	Cost	Source	
Electricity	$0.054 per kWh	Alberta Agriculture and Forestry, Average Farm Input Prices	5-year average cost (December 2013-November 2018)
Natural Gas	$2.86 per GJ	Alberta Agriculture and Forestry, Average Farm Input Prices	5-year average cost (December 2013-November 2018)
Labour	$29.60 per hour	Egg Farmers of Alberta	Alberta Egg Farm Labour
Tractor Rate	$31.53 per hour	2018-19 Farm Machinery Custom and Rental Rate Guide, Government of Saskatchewan	Front wheel assist 120 hp tractor
Urea 46-0-0	$0.48 per pound	Alberta Agriculture and Forestry, Average Farm Input Prices	April 2018 monthly price used ($488.09 per tonne)

To determine the economic implications of incorporating a dryer system into a layer barn, the following variables were analysed:

- Revenue was generated based on the market value of the N contained in the manure and the total tons of manure generated in each scenario;
- Belt operation cost was calculated based on the annual energy use in kWh for each scenario and the average kWh electricity cost;
- Drying costs were calculated based on the annual energy use in kWh for each scenario and the average kWh electricity cost;
- Labour costs were calculated based on the annual hours required to move manure from the barn.
- Hauling costs to move the manure from the barn to the storage area were calculated based on the annual hauling equipment hours by the estimated hourly tractor cost.
- Net Present Value (NPV) analysis was calculated to analyze the profitability of installing and operating the belt and drying equipment. NPV determines the present value of the belt and drying systems expected cash inflows minus the system's acquisition and

operating costs. In calculating NPV for the scenarios, the variables shown in table 21 were used.

Table 21. Variables and values used in the the economic analysis.

Variable	Value
Cost of Capital (discount rate)	6%
Salvage value of equipment	$0.00
Life Span	25 years
Annual Maintenance Cost	$250.00
Cost of Capital (discount rate)	6%

- The cost of capital or discount rate determines the present value of future cash flows for the investment at the specified rate of return. Calculating the value of future cash flows in today's dollars' aids in determining whether the initial capital investment decision should be made. The discount rate considers the opportunity cost of capital and is the rate of return the investment could earn if invested in an alternative project in this case. Based on the literature review, a discount rate of 6% was used for the cost of capital investment. A study on supply-managed sectors referenced the same discount rate for egg producers and dairy producers. A Statistics Canada and AFAC study on the farming rates of return compared to other industries listed a discount rate of 9.6% for dairy; 6.1% for grain; and 4.7% for hog farms.
- Capital cost of the equipment on a per bird basis was estimated at a range of $3.50 to $5.00 per bird. In the NPV analysis, three capital cost estimates were used: $3.50 per bird; $4.25 per bird; and $5.00 per bird. These capital costs were calculated based on the maximum bird population for each barn in the project.

Analysis Discussion

The annual gross revenue, which is an average of the two testing periods, generated from the use of the belt and drying system in the two barns are shown in Figures 17 and 18. The gross revenue calculations do not take into account operational, maintenance or capital costs associated with the belt and drying systems. The annual gross revenue for each scenario was calculated using the pounds of N produced by the N market value.

The annual values for Farm A indicate that all manure removal intervals under the no drying scenarios provided a higher return as compared to corresponding removal intervals under the 10-

and 20-hour drying scenarios. It is important to note that the annual values are the sum of the summer and winter testing periods based on the N content of the manure. Variability in the manure content and the natural bird loss from the summer to winter period, that affected the total manure produced, affected the net market value of N in the manure.

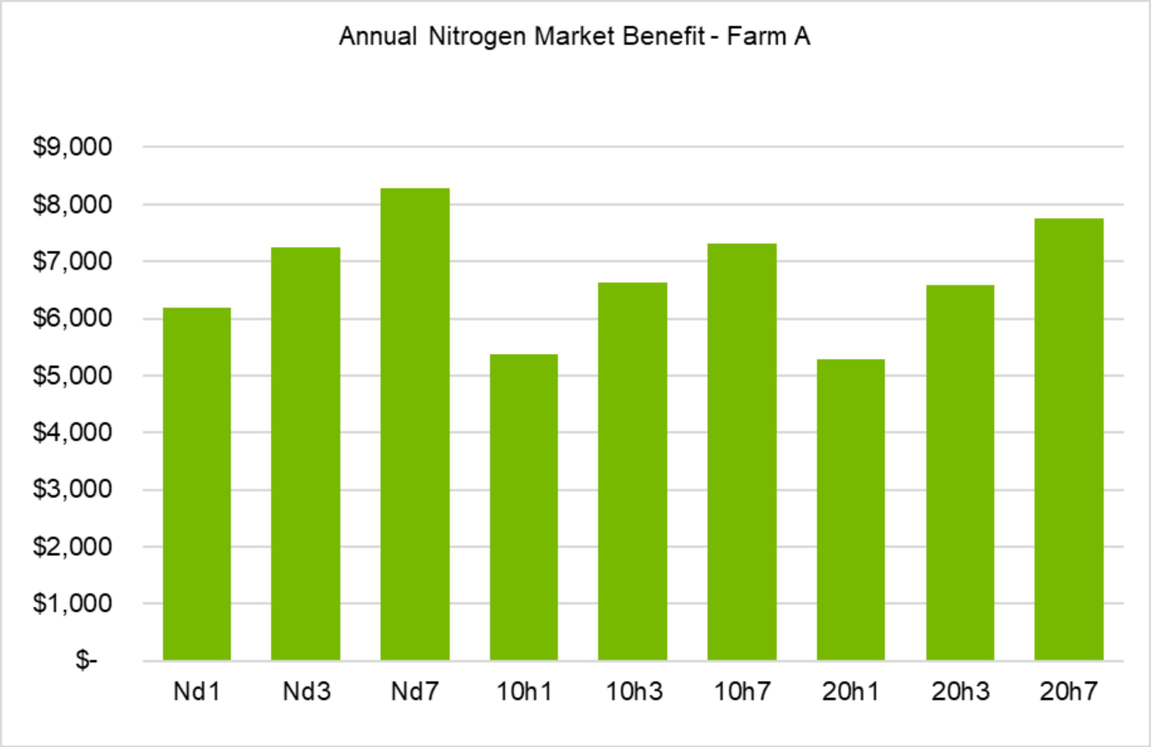

Figure 17. Farm A annual nitrogen gross market value

For Farm F, the N gross market value is highest with the 10- and 20-hour drying scenarios at the 7-day manure removal intervals. This increase in the annual value is associated with an increase in both manure N levels with drying (summer scenario) and manure weights due to increased litter from the younger flock (winter scenario).

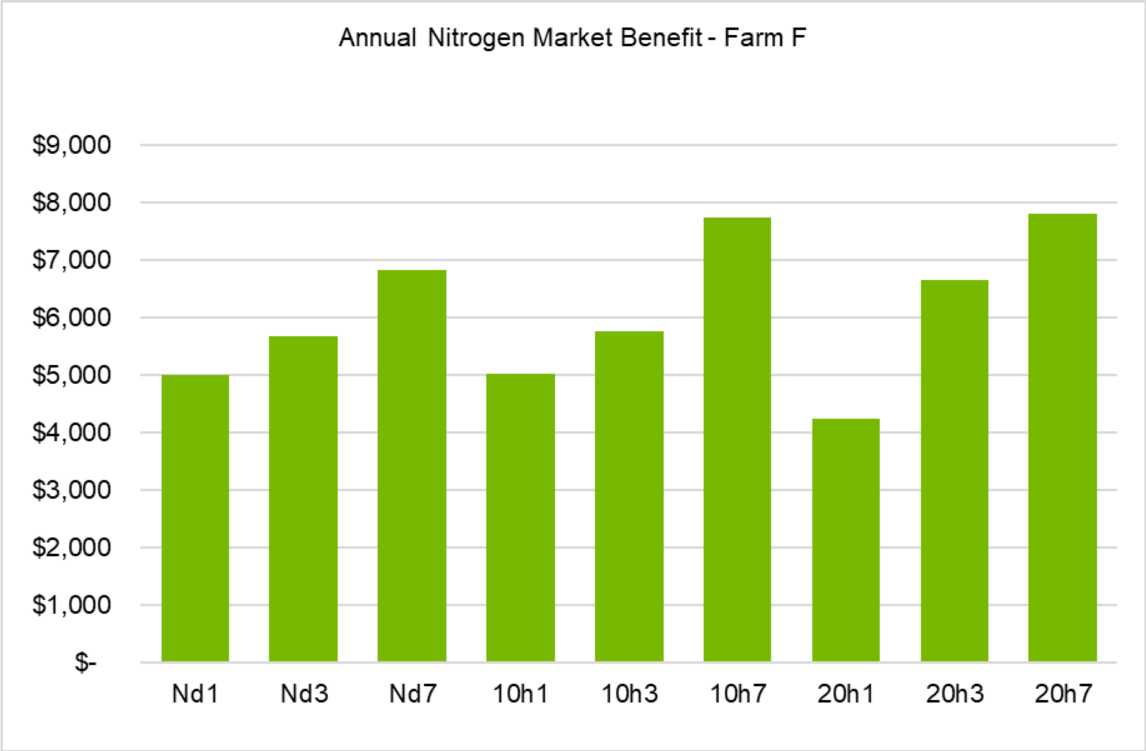

Figure 18. Farm F annual nitrogen gross market value

Figures 19 and 20 display the associated average annual cost for the drying system on a per bird basis for each farm. For Farm A, the average cost per bird ranged from a high cost of $0.85 when manure was dried for 20 hours and removed daily to a low cost of $0.37 when manure was not dried and removed on a 7-day removal frequency (Figure 19). The one-day removal frequency costs were much higher than the other removal frequency due to the labour and hauling involved on the day to day basis. The no drying scenario with a removal frequency of 7-days resulted in the lowest cost due to the reduced labour, hauling and energy costs.

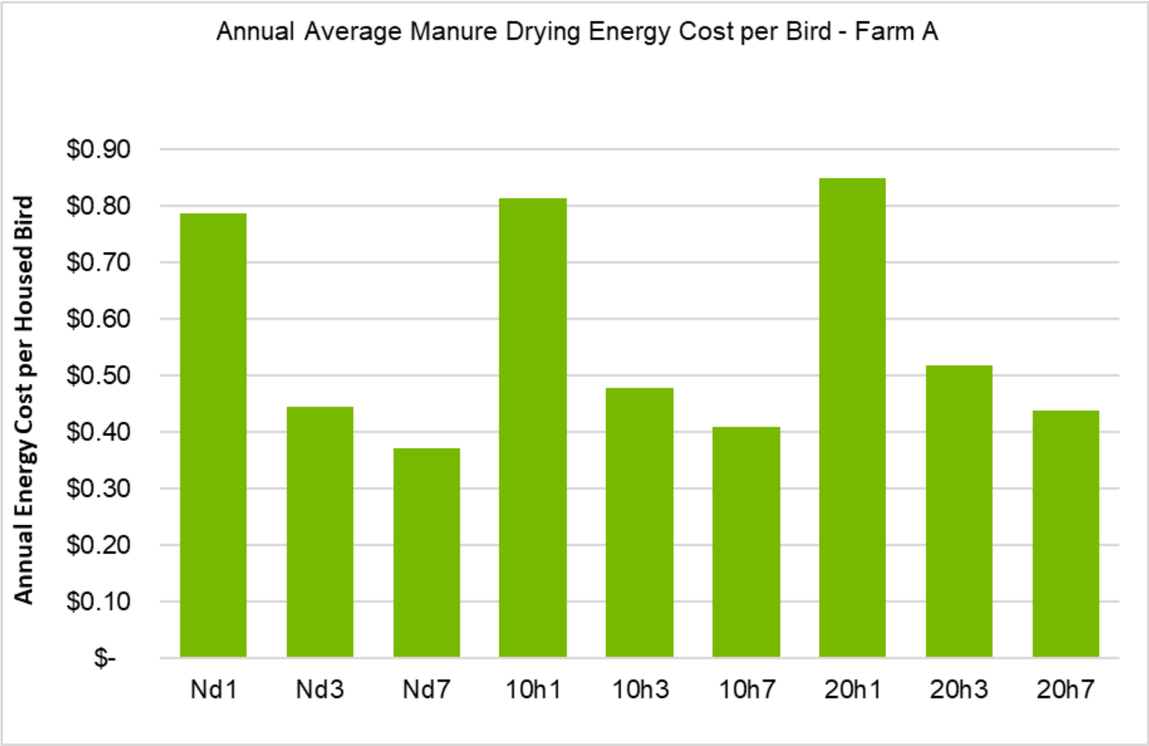

Figure 19. Farm A annual manure drying energy use cost on a per bird basis.

For Farm F, the average cost per bird ranged from $1.10 when manure was dried for 20 hours and removed daily to a cost of $0.46 when manure was not dried and removed on a 7-day removal frequency (Figure 20). The results at Farm F were similar to Farm A in that the one-day removal frequency resulted in a substantially higher cost per bird. The lowest costs were found with the 7-day removal frequencies.

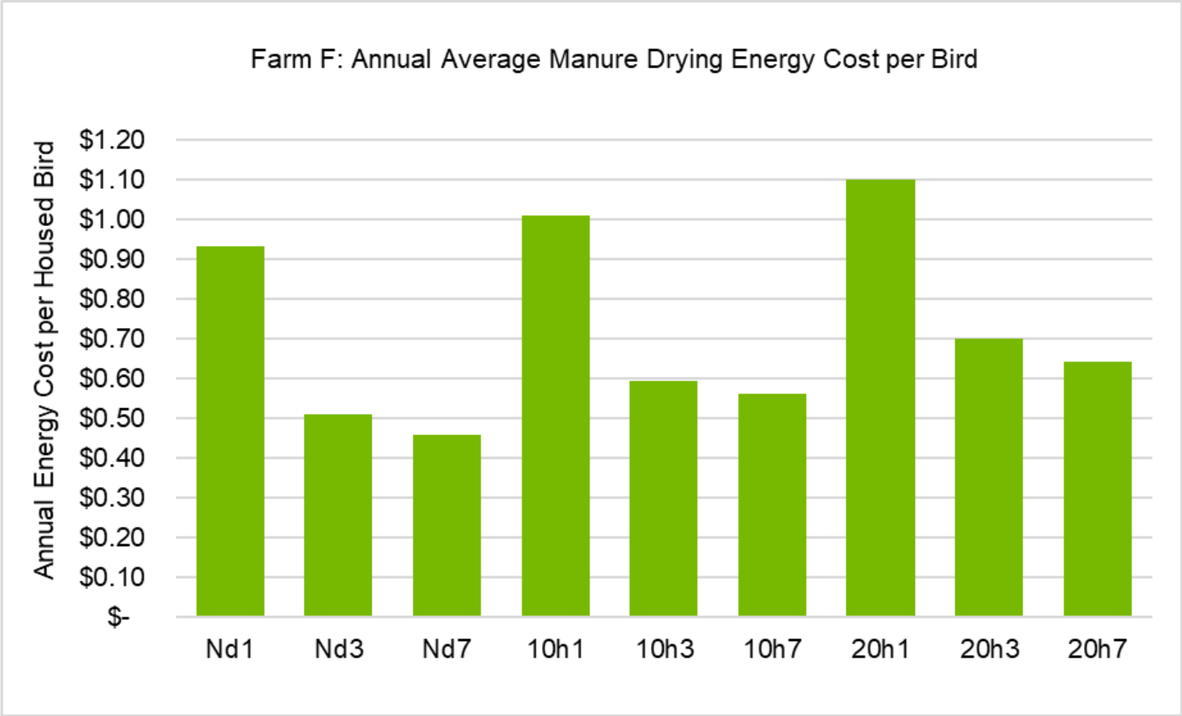

Figure 20. Farm F annual manure drying energy use cost on a per bird basis.

Figures 21 and 22 show the annual net operational loss or gain after considering the market benefit for the produced N and the operational costs (electricity, natural gas, labour and hauling costs). These values do not consider the capital cost associated with the belt and drying system. When looking at the net operational losses or gains, again the one-day removal frequencies resulted in a loss for both farm due to the daily labour and hauling involved. Marginal gains were seen at both farms with the reduced removal frequencies (3-day and 7-days). The highest gain at both farms was found with the no drying, 7-day removal frequency.

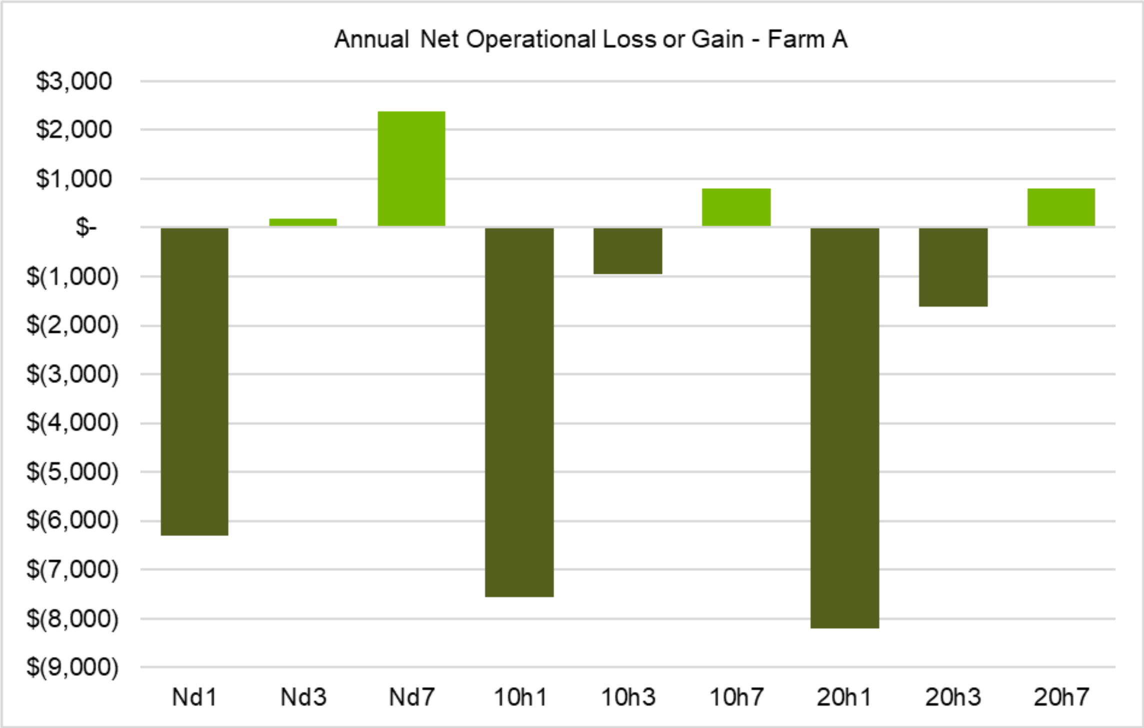

Figure 21. Farm A annual net nitrogen market value.

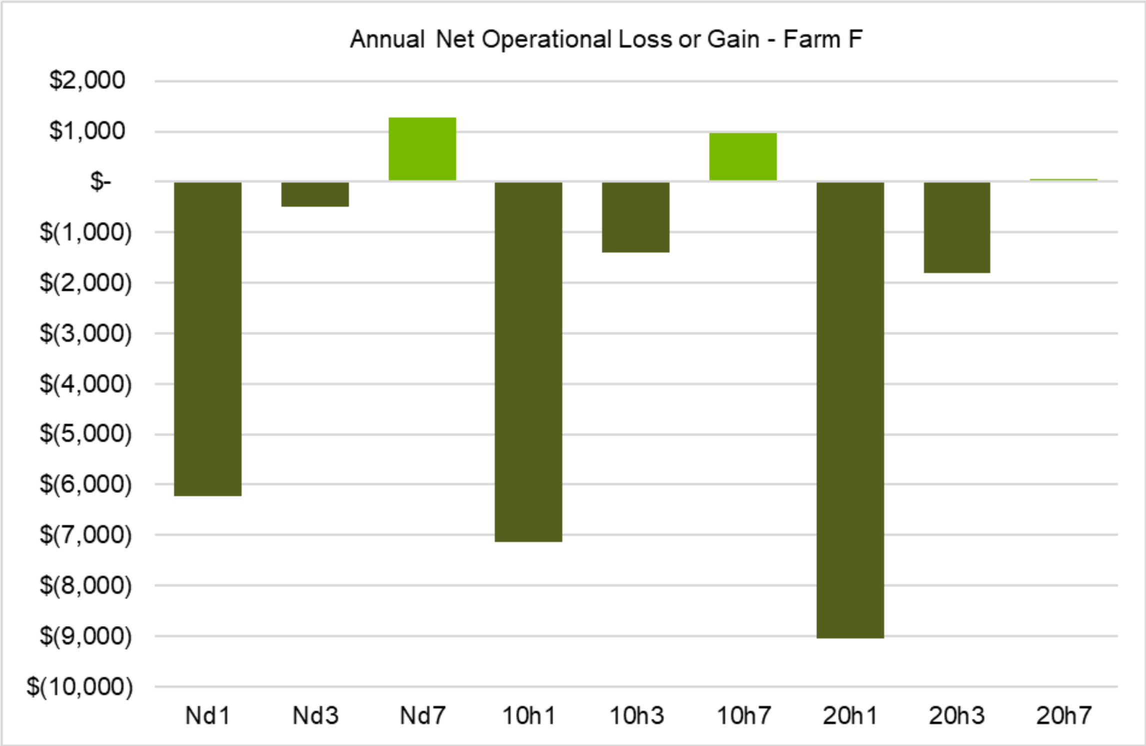

Figure 22. Farm F annual net nitrogen market value.

The net present value calculations shown below analyze the profitability of the belt and dryer system investment for the barns in this project. The annual results, inclusive of both the summer and winter scenarios, for Farm F and Farm A are shown in table 22. These calculations take into account the cost to buy the dryer, annual operation (energy costs; natural gas and electricity), maintenance, value of N in manure, labour cost, and hauling cost.

For each farm, the initial capital cost of the drying system was estimated at a range of $3.50 to $5.00 per bird. To reflect the potential for competition in the marketplace for poultry barn drying systems, the NPV analysis was completed with the initial capital cost of the equipment at a low, mid and high cost point. The capital cost figures used in the analysis were $3.50 per bird, $4.25 per bird and $5.00 per bird (table 22). The total capital cost of the dryer system is based on the maximum bird population for the layer barn; for Farm A this is 20,000 birds and for Farm F this is 12,162 birds.

NPV improves as the number of days between manure removal increases due to a larger volume of manure produced but also the cost savings of lower labour and hauling costs, however all scenarios result in a negative NPV.

Table 22. Net present value analysis for Farm A and Farm F at $3.50/bird, $4.25/bird and $5.00/bird capital cost.

	Removal Frequency	1 day	3 days	7 days[z]	1 day	3 days	7 days
Cost per bird	Drying Hours		Farm A			Farm F	
$3.50/bird	No drying	($153,629)	($70,767)	($42,887)	($125,365)	($51,912)	($29,426)
	10 hours	($169,761)	($85,314)	($63,046)	($137,113)	($63,762)	($33,414)
	20 hours	($177,955)	($93,982)	($63,020)	($161,350)	($68,824)	($44,945)
$4.25/bird	No drying	($153,629)	($70,767)	($42,887)	($125,365)	($51,912)	($29,426)
	10 hours	($169,761)	($85,314)	($63,046)	($137,113)	($63,762)	($33,414)
	20 hours	($177,955)	($93,982)	($63,020)	($161,350)	($68,824)	($44,945)
$5.00/bird	No drying	($183,629)	($100,767)	($72,887)	($143,608)	($70,155)	($47,669)
	10 hours	($199,761)	($115,314)	($93,046)	($155,356)	($82,005)	($51,657)
	20 hours	($207,955)	($123,982)	($93,020)	($179,593)	($87,067)	($63,188)

[z] The removal frequency during the winter testing was reduced to six days.

The NPV results show how small variations in bird population, N levels in the manure or higher drying costs affect the financial viability of the entire investment. More frequent removal of manure at the one and three day increments resulted in higher costs of labour, energy and hauling. The higher cost associated with more frequent removal typically resulted in substantially higher negative NPV outcomes, specifically for higher initial system installation costs, signalling the investment should be reconsidered. Future research considerations of factors beyond the scope of this project, such as the environmental benefits to the bird population from more frequent removal may have a significant impact on the financial investment analysis of a manure belt drying system.

9.0 Summary of Key Learnings and Observations

Going into this project there was an expectation that manure belt dryers would reduce the amount of NH_3 volatilization from the freshly excreted manure, resulting in improved in-barn air quality. Results from the in-barn testing suggested that to minimize the average NH_3 levels in the barn, increasing the frequency of manure removal was more effective than additional drying. Emptying every three days resulted in lower NH_3 levels in the barns as compared to 20 hours of drying with six or seven day removals for both Farm A and Farm F. However, it is important to note that manure drying did provide up to a 50% reduction in maximum in-barn NH_3 concentrations during some scenarios from the winter testing. Another expectation found to be true was that higher in-barn NH_3 concentrations would be typical during winter months, thus removal frequency should be increased during the winter months as compared to the summer.

During the baseline farm visits prior to in-barn testing, staff found several producers were using in-barn NH_3 sensors to monitor and record NH_3 concentrations. Both Farm A and Farm F were fitted with sensors of the same make and model for the sake of comparable data. As several scientific papers suggested, NH_3 monitoring equipment is not consistently reliable. Instantaneous readings were taken once per day at both farms to correlate logged sensor data. As determined early in the summer testing, the manufacturer supplied NH_3 meters were not consistently accurate and did not respond quickly to changing barn conditions. Another key learning was in-barn NH_3 levels dropped very quickly once the manure had been emptied from the barn, particularly during the summer, likely due to higher ventilation rates. In the winter, the NH_3 levels also dropped quickly after removal but not to the extent it did in the summer. At Farm A, data suggested that the manure in the litter had more of an effect on NH_3 levels during the winter months as compared to the summer, which may indicate a need for increased litter management during the winter in aviary barns.

Reduction in manure moisture content can have several benefits including reduction of in-barn NH_3 levels and odour, reduction of manure weight and volume for hauling while also allowing for cleaner belts during everyday use and barn cleanout at the end of the laying cycle. Summer manure moisture content results suggest that manure moisture is affected more by other factors, such as barn temperature, outside temperature, humidity and ventilation, more than manure belt drying at Farm A. At Farm F, drying had a significant impact on moisture content with 20 hours of drying resulting in the lowest moisture content at the 3- and 7-day removal frequencies. In winter, manure drying resulted in significant manure moisture reductions between each treatment, with 20 hours of drying resulting in the lowest moisture content at both farms. As the barn temperatures and conditions were more consistent and stable during the winter, the reductions in moisture content can clearly be linked to the addition of manure drying.

Theoretically, manure belt drying would result in reduced NH_3 volatilization of the freshly excreted manure, which in turn would result in a higher nutrient content manure. Also in theory, producers would be taking advantage of this higher nutrient manure and handling and storing it in a manner, which maintained that N content as much as possible prior to land applying as part of their cropping practices. Statistical analyses indicated there were no statistically significant trends in the N results from either farm. However, taking into consideration the reduction of in-barn NH_3 reported and some small increases in N content, it can be inferred that some level of N is retained. To quantify the retained N, a more controlled study would be necessary that compared scenarios simultaneously to remove some of the variability introduced by the scale of a commercial barn.

One question producers had regarding manure drying was whether it would increase the dust levels in-barn. Data trends from both farms showed the correlation between bird activity and dust levels and suggested that dust did not increase with the use of manure belt dryers. Though the in-barn dust levels were higher in the winter as compared to the summer, this can likely be associated with the reduced ventilation rates during the winter testing. Dust levels were higher at Farm A, as compared to Farm F, as would be expected likely due to extra bird activity and the dry floor litter of the aviary system. A literature review shows the dust levels found in these two barns are comparable to results found from research in barns in the United States.

Energy and power usage was monitored in both barns for the dryer fans and manure belts. The energy consumption of the manure belts during removal was negligible, with the dryer fans requiring more power. As the energy consumption for the removal belts was considerably less than the drying fans, energy could be saved by more frequent removals as opposed to drying. Although the dryer fans required more power, the increase in annual operating costs to the producers was insignificant when comparing drying to no drying.

The N gross market value was greatly influenced by the manure nutrient content and weights, which varied depending on the age of the flock. The annual gross revenue generated from scenario data suggested the annual N market value increased as the number of days between manure removal increased, as there is more accumulated manure. The data also suggested that younger flocks produce more manure, which also has higher N contents. Analysis of the average annual energy cost on a per bird basis for both farms indicated the 1-day removal frequency resulted in the highest cost due to the increased labour and hauling requirements as compared to the 3- and 7-day removal frequencies. Net operational losses or gains were also heavily influenced by the increased labour and hauling requirements for the 1-day manure removals. Annual net operational gains were found at both farms with the 3- and 7-day removals for the no drying, 10-hours and 20 hours drying scenarios. The interaction of days between removal and hours of drying led to an increase in the pounds of N per ton of manure at both farms. Through the drying process, an increase was seen in the concentration of N in the manure as moisture was removed, which led to a higher economic value of the manure. The NPV results show how small variations in bird population, N levels in the manure or higher drying costs affect the profitability of the entire investment. More frequent removal of manure at the 1- and 3-day increments resulted in higher costs of labour, electricity and hauling. The higher cost associated with more frequent removal typically resulted in a negative NPV outcome, specifically for higher initial system installation costs.

Although the egg producers see a value in the manure as a crop amendment, they were not as concerned with the final nutrient content of the manure as they were with in-barn air quality and manure weight or initial transportation costs. The perceived purpose for drying the manure was to reduce NH_3-N loss, improving in-barn air quality and the N content of the manure as well as reducing the moisture content and therefore the weight of the manure, reducing transportation and application costs. Producers were operating the dryers to dry the manure and then transport that manure from the barn to an uncovered field or yard storage site until the manure was spread. The stored manure would be exposed to the elements, absorbing moisture thus negating some of the benefits achieved by the drying (a lighter product and better NH_3-N retention). The realized benefit of the manure dryer was primarily in the improved in-barn air quality and possibly to reduce initial transportation costs. It appeared the benefit of the manure dryers ended when the manure leaves the barn and gets piled in the field. To get the maximum value of the dried manure, it must be stored in covered storage to reduce moisture absorption and N lost to the environment.

In summary, manure belt dryers are a management tool. When producers are deciding whether to invest in a manure dryer system, they should consider:

- how they operate their barn,
- whether they have limitations in time and labour,
- if there are any conditions in particular they have to deal with or would like to manage differently,
- and how they manage manure after it leaves the barn.

Results show that manure dryers can reduce manure moisture content, thereby reducing in-barn NH_3. However, results also show that simply increasing the manure removal frequency has more impact, in terms of reducing in-barn NH_3, than manure drying. Also, if manure N is valued, manure management and handling after the manure is removed from the barn becomes more important.

Through the course of the project as the various cause and effect relationships began to emerge, it became clear that making the decision whether to invest in manure drying systems or not comes down to personal preference regarding in-barn conditions and management.

Since launch of the PEEP environmental program, scores remained relatively low in manure treatment, which emphasized a need to address extension activities related to manure management practices. Based on the project results, EFA made the decision to change the PEEP manure treatment questions to focus more on manure use in field applications.

10.0 Future Research

Potential future work could include the following areas:

- To quantify the retained N a more controlled study would be necessary that compared scenarios simultaneously to remove some of the variability introduced by the scale of a commercial barn.
- As learned in a Flock Talk session held by EFA, producers are being urged to monitor CO2 rather than NH_3, by equipment suppliers, supposedly due to better monitoring sensors and the correlation between the two. This should be investigated further.
- Point source ammonia emissions from the barn.
- External dryers, if regulations came into play that encouraged the use of external dryers what would that look like for current barn design/retrofit options

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12.0 References

[1] E. D. I. K. J. Z. B. A. T. B. R. a. F. A. M. T. Jasper L. T. Heerkens, "Specific characteristics of the aviary housing system affect plumage condition, mortality and production laying hens," *Poultry Science,* July 2015.

[2] R. Peijs, "British poultry industry alarmed by cage-eggs ban," *Poultry World,* p. 1, 5 September 2016.

[3] Egg Farmers of Canada, "Egg Farmers of Canada announces industry-wide transition away from conventional housing," 5 February 2016. [Online]. Available: http://www.eggfarmers.ca/press/egg-farmers-of-canada-announces-industry-wide-transition-away-from-conventional-housing/. [Accessed 03 08 2017].

[4] H. T. a. D. Zbeetnoff, "Evaluation of Options for Alberta Layer Waste Utilization," Timmenga & Associates Inc., Vancouver, 2012.

[5] J. Knutt, "Use of Manure Drying Belts in Layer Barns," 2015.

[6] C. Coufal, C. Chavez, P. Niemeyer and J. Carey, "Nitrogen emissions from broilers measured by mass balance over eighteen consecutive flocks," *Poultry Science,* vol. 85, pp. 384-391, 2006.

[7] C. W. Ritz, B. D. Fairchild and M. P. Lacy, "Implications of Ammonia production and emissions from commercial poultry facilities: A review," *Poultry Science Association,* vol. 13, pp. 684-692, 2004.

[8] P. Groot Koerkamp, "Review on emissions of ammonia from housing systems for laying hens in relation to sources, processes, building design and manure handling," *Journal of Agricultural Engineering Research,* vol. 59, pp. 73-87, 1994.

[9] A. Atia, "Alberta Agriculture and Forestry," june 2006. [Online]. Available: https://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex8271. [Accessed 27 July 2018].

[10] T. a. B. J. Aziz, "Poultry World," 25 October 2010. [Online]. Available: https://www.poultryworld.net/Breeders/Health/2010/10/Harmful-effects-of-ammonia-on-birds-WP008071W/. [Accessed 5 September 2018].

[11] National Farm Animal Care Council, "Code of Practice - For the Care and Handling of Pullets and Laying Hens," National Farm Animal Care Council and Egg Farmers of Canada, Ottawa, 2017.

[12] T. Hein, "How the Canadian laying hen housing landscape is changing and why," *The Poultry Site,* 17 May 2016.

[13] Wikipedia, "Wikipedia The Free Encyclopedia," 12 November 2017. [Online]. Available: https://en.wikipedia.org/wiki/Battery_cage. [Accessed 27 November 2017].

[14] Egg Farmers of Canada, "Code of Practice for the Care and Handling of Pullets and Laying Hens," Egg Farmers of Canada, Ottawa, 2017.

[15] A. Ghaly and M. Alhattab, "Drying poultry manure for pollution potential reduction and production of organic fertilizer," *American Journal of Environmental Science,* vol. 9, no. 2, pp. 88-102, 2013.

[16] Egg Farmers of Alberta, "Egg Farmers of Alberta," Cornerstone Digital, 2017. [Online]. Available: http://eggs.ab.ca/farming/hen-housing/free-run-aviary-housing/. [Accessed 27 November 2017].

[17] P. G. Koerkamp, J. Raaben, L. Speelman and J. Metz, "Litter composition and ammonia emission in aviary houses for laying hens: Part III, water flow to the litter through fresh droppings," *Journal of Agricultural Engineering Research,* vol. 73, pp. 363-371, 1999.

[18] E. M. a. M. B. SG Wiedemann, "Layer hen manure analysis report," Australian Egg Corporation Limited, Sydney, 2008.

[19] P. Groot Koerkamp, "Review on emissions of ammonia from housing systems for laying hens in relation to sources, processes, building design and manure handling," *Journal of Agricultural Engineering Research,* vol. 59, pp. 73-87, 1994.

[20] T. Ormann, "Manure nutrient value: Wisdom gained from experience in Southern Alberta," 20 January 2005. [Online]. Available: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/epw9921. [Accessed 18 September 2017].

[21] F. a. R. D. Manitoba Agriculture, "Properties of Manure," November 2015. [Online]. Available: https://www.gov.mb.ca/agriculture/environment/nutrient-management/pubs/properties-of-manure.pdf. [Accessed September 2017].

[22] D. S. a. P. T. D. Ruiz-Diaz, "Farm Journal's AG PRO," 22 December 2013. [Online]. Available: http://www.agprofessional.com/resource-centers/crop-fertility/phosphorus-potassium/news/Nutrient-availability-and-value-of-poultry-litter-236934051.html. [Accessed September 2017].

[23] M. Vlug, Interviewee, *Project Manager Jansen Poultry Equipment.* [Interview]. 11 January 2016.

[24] M. Czarick, "Commercial Layer House Ventilation Systems," [Online]. Available: https://www.poultryventilation.com/sites/default/files/presentations/layer.pdf. [Accessed 9 August 2017].

[25] J. Yang, E. Huffman, C. Drury and X. a. D. J. R. Yang, "Estimating the impact of manure nitrogen on total nitrogen application on agricultural land in Canada," *Canadian Journal of Soil Science,* vol. 91, no. 1, pp. 107-122, 2011.

[26] Novenco , "CNA-CNB Centrifugal Fans Standard Temperatures and EX," [Online]. Available: http://www.novenco-building.com/media/14211/cna-cnb-cat-gb-mu15544.pdf. [Accessed 28 07 2017].

[27] SAS Institute Inc. , *The SAS System for Windows release 9.4.,* Cary, North Carolina, United States., 2002-2012.

[28] O. S. &. Health, "United States Department of Labor - Occupational Safety & Health Administration," 2008. [Online]. Available: https://www.osha.gov/dte/library/silicosis/silica_nep_2008_employer_prof/slide14.html. [Accessed 25 March 2019].

[29] Y. Zhao, T. Sheperd and H. a. X. H. Li, "Environmental assessment of three egg production systems - Part I. Monitoring system and indoor air quality," Poultry Science, 2015.

[30] S. Bouquin and S. a. M. V. Martin, "Aerial dust concentrations in cage-housed, floor-housed, and aviary facilities for laying hens," Poultry Science, 2013.

[31] R. S. Gates, H. Xin , K. D. Casey, Y. Liang and E. F. Wheeler , "Method for Measureing Ammonia Emissions from Poultry Houses," *Poultry Science Association,* 2005.

[32] D. N. Patni, "Ammonia Concentrations and Losses in Large Layer Barns," Agricultrue and Agri-Food Canada, Factsheet #109.

[33] R. Carew, "Ammonia emissions from livestock industries in Canada: Feasibility of abatement strategies," *Environmental Pollution,* vol. 158, pp. 2618-2626, 2010.

[34] H. Li, "Ammonia emissions from manure belt laying hen houses and manure storage," Iowa State University, 2006.

[35] J. Broucek and B. Cermak, "Emission of harmful gases from poultry farms and possibilities of their reduction," *Ekologia,* vol. 34, no. 1, pp. 89-100, 2015.

[36] OECD, "Environmental Performace of Agriculture in OECD Countries since 1990," 2008.

[37] S. Wang, L. Zhao, X. Wang, R. B. Manuzon and H. Li, "Estimation of ammonia emissions from manure belt poultry layer houses using an alternative mass balance method," in *2009 ASABE Annual International Meeting*, Reno, NV, 2009.

[38] M. Prasanthrajan and P. Doraisamy, "Reducing the ammonia volatilization from poultry droppings by temporary immobilization and drying," *International Journal of Chemical, Environmental & Biological Sciences,* vol. 1, no. 4, pp. 682-684, 2013.

[39] F. Nicholson, B. Chambers and A. Walker, "Ammonia emissions from broiler litter and laying hen manure management systems," *Biosystems Engineering,* vol. 89, no. 2, pp. 175-185, 2004.

[40] P. Yang, J. C. Lorimor and H. Xin, "Nitrogen losses from laying hen manure in commercial high-rise layer facilities," *Transactions of the ASAE,* vol. 43, no. 6, pp. 1771-1780, 2000.

[41] Y. Liang, H. Xin, E. Wheeler and J. Zajaczkowski, "Ammonia emissions from U.S. laying hen houses in Iowa and Pennsylvania," Agricultural and Biosystems Engineering Publications, Iowa State, 2005.

[42] H. Xin, R. Gates, A. Green, F. Mitloehner, P. Moore and C. Wathes, "Environmental impacts and sustainablity of egg production systems," *Poultry Science,* vol. 90, pp. 263-277, 2011.

[43] H. Xin, M. Hayes, M. Ibarburu, S. Millman, R. Parsons, B. Brehm-Stecher, H. Kim and H. Li, "A comprehensive assessment of aviary laying-hen housing system for egg production in the Midwest," Agricultural and Biosystems Engineering Publications, 2012.

[44] J. Knutt, "Use of manure drying belts in layer barns," Lethbridge, 2015.

[45] E. a. C. C. Canada, "Canadian Environmental Sustainability Indicators: Air Pollutant Emissions," 2016.

[46] T. Hein, "How the Canadian Laying Hen Housing Landscape is Changing- and Why," *The Poultry Site,* 17 May 2016.

[47] M. H. R. S. R. W. a. V. P. C.M. Wathes, "Concentrations and emission rates of aerial ammonia, nitrous oxide, methane, carbon dioxide, dust, and endotoxin in U.K. broiler and layer houses.," *British Poultry Science,* vol. 38, pp. 14-28, 1997.

[48] D. E. a. D. G. H.M. Keener, "NH3 emissions and N-balances for a 1.6 million caged layer facility: Manure belt/composting vs. deep pit operation.," *Transactions of the ASAE. American Society of Agricultural Engineers,* vol. 45, no. 6, pp. 1977-1984, 2002.

[49] E. a. C. C. Canada, "Canadian Environmental Sustainability Indicators: Air Pollution Emissions," 2016.

[50] R. Carew, "Ammonia emissions from livestock industries in Canada: Feasibility of abatement strategies," *Environmental Pollution,* pp. 2618-2626, 2010.

[51] P. Yang, J. Lorimor and H. Xin, "Nitrogen losses from laying hen manure in commercial high-rise layer facilities," *Transactions of ASAE,* vol. 43, no. 6, pp. 1771-1780, 2000.

[52] W. Kroodsma, R. Scholten and J. Huis in' Veld, "Ammonia emissions from poultry housing systems," 1988.

[53] H. Keener, D. Elwell and D. Grande, "NH3 emissions and N-balance for a 1.6 million caged layer facility: Manure belt/composting vs. deep pit operation," *Transaction of the American Society of Agricultural Engineers,* vol. 45, no. 6, pp. 1977-1984, 2002.

[54] F. Nicholson, B. Chambers and A. Walker, "Ammonia emissions from broiler and laying hen manure management systems," *Biosystems Engineering,* vol. 89, no. 2, pp. 175-185, 2004.

[55] P. Groot Koerkamp, L. Speelman and J. Metz, "Litter Composition and Ammonia Emission in Aviary Houses for Laying Hens. Part 1: Performance of a Litter Drying System," *Journal of Agricultural Engineering Research,* vol. 70, pp. 375-382, 1998.

[56] P. Groot Koerkamp, A. Keen, T. Ven Niekerk and S. Smit, "The effect of manure and litter handling and indoor climatic conditions on ammonia emissions from a battery cage and an aviary housing system for laying hens," *Journal of Agricultural Science,* vol. 43, pp. 351-373, 1995.