Determining the Relationships between Feed Efficiency, Production Traits, and Greenhouse Gas Emissions in Turkeys

by

Clayton Wilem Gionet

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ABSTRACT

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Clayton Wilem Gionet
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Advisor: Dr. Bill Van Heyst

Poultry production is a contributor to air pollution emissions and the release of direct and in-direct greenhouse gases. This study examines the effect that the feed conversion ratio (FCR), a production trait used for selection of turkey breeding stock, has on the generation of methane and carbon dioxide and the in-direct greenhouse gas, ammonia. To assess the potential differences in pollutant emissions, two groups of turkeys with different production traits were monitored in environmental chambers. The two groups were separated by their FCR. The group with a high efficiency FCR yielded methane, ammonia and carbon dioxide emission factors of 2.30 (± 3.73), 0.574 (± 0.362), and 4.67x10^4 (± 1.59x10^4) g/day/AU. The emission factors for the low efficiency group were 3.46 (± 5.54), 0.971 (± 0.569), and 6.54x10^4 (± 2.19x10^4) g/day/AU. However, the methane results are not statistically significant. Birds from the lower efficiency genetic line produced on average: 40.1%, 51.2% , and 33.2% more CH₄, NH₃, and CO₂ over the sampling campaign. At the end of the trial, the average body weight for high efficiency birds was 17.9 (± 2.42) kg, and 12.1 (± 0.992) kg for low efficiency birds. By implementing genetic selection targeted for improving FCRs, the industry will be moving to a more sustainable practice by reducing overall emissions, while producing more kg of meat per bird.
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List of Abbreviations

Animal Care Committee – ACC

ACGIH - American Conference of Governmental Industrial Hygienists

CH₄ - Methane

CO₂ – Carbon Dioxide

CPRC – Canadian Poultry Research Council

EF – Emission Factor

EIPPCB - European Integrated Pollution Prevention and Control Bureau

FANS - Fan Assessment Numeration System

FCR – Feed Conversion Ratio

FID - Flame Ionization Detector

GHG – Greenhouse Gas

IPCC - Intergovernmental Panel on Climate Change

IR - Infrared

K - Potassium

N - Nitrogen

N₂O – Nitrous Oxide

NDIR - Nondispersive infrared

NH₃ - Ammonia

NH₄-N – Ammonium

NIOSH - National Institute for Occupational Safety and Health

NMHC – Non-Methane Hydrocarbons

NO – Nitrogen Oxide

NO₂ - Nitrogen dioxide

O₃ – Ozone
OMAFRA – Ontario Ministry of Agriculture, Food and Rural Affairs

P – Phosphorus

PAS - Photoacoustic signals

ppb – parts per billion

ppm – parts per million

RH – Relative Humidity

STC - Spontaneous turkey cardiomyopathy

TKN - Total Kjeldahl Nitrogen

TWA – Time weighted Average

US EPA – Environmental Protection Agency

VOC - volatile organic compounds
1. Introduction

Poultry production is a significant contributor to air pollution and the release of contaminants into the atmosphere. As human population increases, the demand for food availability increases as well, leading to growth in the agricultural sector. Between 1970 and 2014, global turkey stocks increased from approximately 178 million to over 461 million birds or by 259% (FAOSTAT, 2016). Turkey production in Canada has seen consistent increases, with 168,400 tonnes of turkey meat produced in 2013, up from 127,900 tonnes recorded previously in 1993 (FAOSTAT, 2016). In 2012 it was estimated that turkey production in Canada accounts for roughly 2.8% of world production, which was 5,600,000 tonnes (FAOSTAT, 2012).

To meet the increasing demand for food, livestock operations are becoming larger and more concentrated. These expansions increase production efficiency, but result in greater emissions of contaminants and particulates. As expected with increased emissions, there is concern for the health of the human workers, concern for livestock health, and accumulating concerns associated with environmental impact issues. As a result, it is important for the livestock sector to look at mitigation strategies in order to reduce contaminant emissions.

Poultry productions’ most significant emissions include ammonia (NH$_3$), nitrous oxide (N$_2$O), carbon dioxide (CO$_2$), and methane (CH$_4$). CH$_4$ and N$_2$O emissions are significantly lower than CO$_2$; however, they have severe global warming potentials. CH$_4$ and N$_2$O have climate change potential of 28 and 298 times that of CO$_2$, respectively (Epa.gov, 2017). Studies have examined the emission factors from several poultry facilities (Van Der Hoek, 1998; Asman, 2001; Gay et al., 2005; Guiziou, and Béline, 2005; Li et al., 2011; Wood and Van Heyst 2016) however; there is an evident information gap on the production emissions from turkeys, making it an important area to examine.

NH$_3$ is formed as a result of nitrogenous compounds found in manure going through microbial degradation. Manure is defined as strictly excreta (feces and urine) while
litter is the inclusion of the excreta and the bedding material. Nitrogen can be found in all excreted animal waste, typically in high levels. Ammonia is an important pollutant because it negatively impacts surrounding air and water quality, as well as posing a threat to animal and human welfare. Evidence points to agriculture as the main source of ammonia emissions to the atmosphere, accounting for up to 90% of the total ammonia emissions in Western Europe (Bussink and Oenema, 1998).

Methane production depends heavily on the manure management system and the conditions in the housing facility. Under anaerobic conditions, the litter pack could produce methane. However, there is limited research into methane emissions from turkey production facilities. Carbon dioxide forms through the normal combustion of fuel in brooder stoves and heaters, as well as through the respiration of the birds. Exposure to high levels of CO₂ can impede turkey health, delay growth and, at high enough levels, cause death.

Emission estimates are typically in the form of emission factors (EFs, units: g/day/AU), which express the quantity of a pollutant that is released to the atmosphere and relates it to an activity level associated with the release of that pollutant (US EPA, 2014). Emission factors are calculated on an animal unit (AU, 500 kg of live weight) basis, which is the activity level associated with livestock production (Roumeliotis et al., 2010a).

There are several mitigation practices currently being evaluated in poultry production. Updated housing facilities are better equipped to reduce direct and indirect greenhouse gas (GHG) emissions by improving heating, lighting, and ventilation efficiency. Manure management practices, such as managing moisture content, frequency of litter removal, and management of built up litter, are being studied or adapted to reduce GHG emissions. These practices are important due to the ability of litter to produce GHGs under certain conditions. Reducing the moisture content and cleaning out the litter more frequently can reduce emissions (Liang et al 2005).
In addition to altering conditions in the barn, reducing GHG emissions from the animal itself may also be significant. Genetic selection based on feed conversion traits would aid in the development of a turkey line that is more efficient in the conversion of feed to mass gained. This is a potentially important mitigation strategy, as it can affect the release of contaminants. This could be achieved by lowering the amount of crude protein from the feed that is unused by the birds and later excreted in the litter. The potential difference in greenhouse gas and ammonia contributions from a turkey with a higher feed conversion efficiency compared to a lower efficiency is the principle concept of study for this thesis.

1.1 Study Objectives

The main objective of this study is to evaluate the effect of FCR on the emission factors of direct and indirect GHG emissions, namely CH$_4$, NH$_3$, and CO$_2$. To achieve this, a monitoring system was setup in an environmentally controlled room where analyzers collected samples from inside two environmental chambers as well as ambient air samples. The system incorporated several analyzers to determine the concentration of the three targeted pollutants. EFs were calculated from the concentrations and expressed as a mass per year per animal unit (AU) basis, where an AU is a representation of 500 kg of live mass.

To monitor GHG emissions based on differing production traits, the turkeys were separated into two groups: high feed efficiency and low feed efficiency. Two turkeys from each group were selected randomly every day to be monitored independently. This project required two enclosed systems wherein the production of GHGs was measured for two turkeys in each chamber. Using calculated feed efficiency and production trait information, a genetic basis for GHG emissions could be determined. Once GHG production is quantified and compared to other measured production traits, the turkey industry will be able to assess its environmental impact on a per bird basis, and have the option of including this in future selection decisions.
1.2 Thesis Outline

A literature review, given in Chapter 2, provides a summary of important parameters and provides background on several factors relevant to the thesis. Such parameters include information on the contaminants (generation mechanisms, health and safety factors, and monitoring practices), turkey facilities, feeding and drinking regimes and management practices, feed conversation rates and selective breeding.

Chapter 3 outlines the analyzers and equipment used to monitor the gases as well as the ventilation rates. Chapter 4 provides details on the facility used, including the penning room and environmentally controlled room, and provides a discussion on the experimental setup. Chapter 5 describes the methods used to for experimental analysis including how results were analyzed.

The results including an in-depth discussion of observed trends and observed outcomes are included in Chapter 6. The related conclusions and recommendations resulting from the study are summarized in Chapter 7 and Chapter 8, respectively.
2. Literature Review

In this Chapter, a literature review is provided to give the necessary background information on all facets of the project. The components include: genetic improvement with a focus on feed conversion ratio (FCR), concepts for genetic selections, and FCR and its effect on greenhouse gas production. A section is devoted to describing the housing of turkeys typical in the industry, manure management, feeding and drinking operations, ventilation, and lighting. With regards to the pollutants monitored, a background is given on their generation mechanisms, health and environmental concerns, the analyzers required to monitor emissions, and a brief overview of their sampling techniques. In addition, a summary of relevant studies is provided and discussed below.

2.1 Genetic improvement

To increase production efficiencies and meet the increasing demand for food, commercial poultry operations are becoming larger, and stocking densities are increasing. This results in increased contaminant and particulate matter emissions. As expected with increased emissions, there is concern for human workers and livestock, as well as accumulating environmental risk.

Agricultural producers are under pressure to reduce impact while increasing production. There are several mitigation practices currently in use throughout the industry, including genetic improvements. Genetic improvements in turkey production are primarily achieved through trait selection. These selections occur in the pure lines of the breeding companies (Willems, Buddiger, & Wood, 2014). Turkey breeders obtain genetic gains through the development of unique lines that combine in a four-way cross (Figure 1). Breeding across these lines eventually provides the commercially available turkey which encompasses traits specific to each genetic line.

Pure lines are arranged into either sire or dam lines. These two subcategories have
differing breeding objectives. For sire lines, the emphasised traits are body weight, breast meat yield, growth rate and feed efficiency. Egg production and fertility traits are targeted for dam lines (Willems et al., 2014). There are also secondary traits that are considered for both lines, albeit at a lower weighting. These include survival, longevity, and traits relating to structural fitness. The economic return for the industry from each genetic line largely dictates the inclusion of traits and their weighting (Wood, 2009).

By modelling the traits in a breeding program accurately, it is possible to maximize the amount, and rate of genetic gain. Therefore, genetic parameters that are estimated, such as genetic variation and genetic correlations and heritability, play a pivotal role in the development of a selection index (Willems et al., 2014). Assessing changes in these parameters over generational breeding is important to the progress in a breeding program, as they are used for the prediction of responses to the selections. Therefore, to guarantee a high level of accuracy of the selection index, these values need to be reproduced and calculated repeatedly (Willems et al., 2014).

Feed efficiency is important to the industry as it has an immediate impact on the economic value of the industry. Feed efficiency traits minimize production costs by reducing the feed required, as well as potentially reducing greenhouse gas emissions. While the genetic parameters are typically well known in the major breeding lines, there are also less important traits in secondary lines that can be researched for future involvement in a breeding program. Because of this, the genetic parameters for novel lines need to be examined independently to assess their potential (Willems et al., 2014).
2.1.1 Feed Conversion Ratio

Feed Conversion Ratio (FCR) is a measure of an animal’s efficiency in converting feed into bodyweight or other desired product, such as eggs for laying chickens. For animals used in meat production, the FCR relates to the output of mass gained. FCR is the mass of the feed consumed, divided by the mass gained, all over a specified time. Feed conversion ratios can be a selected trait for feed efficiency and thus implemented into the breeding program.

Feed requirements are an important consideration in the turkey industry, representing more than half of the total costs of production (Willems et al., 2014). As genetic selection leads to progress in body weight; the amount of feed consumed is expected to increase. This is because larger birds consume more feed (Willems et al., 2014). By improving feed efficiency, breeders can identify animals that require the same amount of feed as their counterparts but will have higher body weight and/or weight gain. This can be valuable in the animal production industry and help to reduce feed cost per kg of meat produced. This can be easily achieved in a breeding program, as genetic selection and improved management practices have led to improved FCRs in
the turkey by approximately 20% between 1966 and 2003 (Willems et al., 2014). A list of FCRs from recent literature for turkey production is provided in Table 1.

Table 1 Comparison of Turkey Feed Conversation Ratio

<table>
<thead>
<tr>
<th>Source</th>
<th>Mean FCR</th>
<th>Population used for estimation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Konca et al. (2009)</td>
<td>3.10</td>
<td>120 turkey toms reared in summer from 4-18 weeks</td>
</tr>
<tr>
<td>Case et al. (2012a)</td>
<td>2.95</td>
<td>16,412 tom turkeys from 15-19 weeks</td>
</tr>
<tr>
<td>Willems et al. (2014)</td>
<td>3.14</td>
<td>13,339 birds from Orlopp primary breeder turkey line</td>
</tr>
<tr>
<td>Milbradt et al. (2014)</td>
<td>1.90 ± 0.09</td>
<td>315 female commercial cross turkeys from 0-70 days</td>
</tr>
<tr>
<td>Tran et al. (2015)</td>
<td>2.19</td>
<td>64 Hybrid Converter tom turkeys (control) from 0-12 weeks</td>
</tr>
<tr>
<td>Tran et al. (2015)</td>
<td>2.07</td>
<td>64 Hybrid Converter tom turkeys (silica-based feed supplement) from 0-12 weeks</td>
</tr>
</tbody>
</table>

2.1.2 Selection concepts for FCR

FCR is moderately heritable in turkeys, therefore selecting FCR as the main criterion for line breeding would improve feed efficiency over generations (Aggrey et al., 2010; Case et al., 2010d; Pakdel et al., 2005). A study (Havenstein et al., 2007), comparing a random bred population (control) with commercially available stock from 1966 and 2003, came to the conclusion that programs using a selection process in conjunction with management techniques improved FCR by approximately 20%. Another study (Havenstein, G., Ferket, P., Scheideler, S., & Larson, B., 1994) compared breeding lines from 1957 and 1991, where the target parameters of the study were nutrition, genetics, and management changes that were implemented over the study period. The results were a drastic improvement of FCR between 1957 and 1991 with the
FCR values being 3.00 and 2.04, respectively. This study used birds of parallel age and weights to achieve these results. (Emmerson, 1997; Havenstein et al., 1994).

2.1.3 GHG and FCR

Limiting poultry production’s environmental impact is a continuing challenge. As world population increases, along with cultural food shifts, poultry production is an expanding market. It has been predicted that globally the consumption of poultry meat will increase by an annual rate of 2.51% from 2000 to 2030 (Fiala, 2008). Even though there has been success in mitigation techniques, both in the management and nutrition, such strategies may not be able to provide the necessary reduction of GHG generation.

Recent studies estimating animal production’s environmental impact for full product life cycle show that poultry levels of NH₃ and GHG emissions are the lowest. The EU-27 European Commission has a total production of 493 teragrams of CO₂ eq per year from livestock farming. Referring to a kg of product, beef is the single largest generator of emissions, representing approximately 35% of all emissions. Poultry only contributes 6% of the CO₂ eq GHG emissions. Beef has the highest GHG emission CO₂ equivalence with 22.6 kg CO₂, while pork has 3.5 kg CO₂ and poultry 1.6 kg CO₂ (Lesschen et al., 2011). In terms of the poultry sector, built up litter is the largest direct contributor to N₂O and CH₄ emissions (Gates et al., 2008; Verge et al., 2009). Figure 2 shows a representation of the EU-27 GHG emissions below.
Feed efficiency has an important role in limiting GHG emissions. As FCRs improve the amount of excreta decreases, which effects GHG emissions in two ways:

1. Enteric fermentation will decrease as feed efficiency improves, lowering N$_2$O and CH$_4$ (Wang and Huang, 2005), and

2. Decreasing amounts of excreta entering the manure storage systems will limit the emissions of GHG (Hill and Azain, 2009; Miles et al., 2006).

A selection experiment that occurred over four generations highlighted these observations. When a line of broilers with a lower FCR was compared to a randomly selected control bred, that line excreted 67.4% less (de Verdal et al., 2010). Similarly, a study from 2011 with an eight-generation selection campaign observed that a more efficient turkey (FCR of 1.72 vs 2.72) had reduced excreta weight by 41.3% (de Verdal et al., 2011). These two studies highlight the opportunity to lower GHG emissions through selective breeding for FCR.

Figure 2 Total greenhouse gas emissions from sources associated with livestock production in the EU-27 (Lesschen et al., 2011)
2.2 Poultry Rearing

Turkeys are typically reared for meat production, which often incorporates a two-phase process. The first phase consists of a brooding period which is completed for all birds up to 4-6 weeks of age, where they will reach an approximate weight of 2 kg. The second phase transfers the birds to different housing for the growth and conditioning phase, typically known as the grow out period. Generally, the toms are slaughtered after the grow out period. This is typically between 16 and 22 weeks, where the birds have reach a live weight range of 14.5 – 21 kg. For hens, the slaughter weight is generally from 7.5 kg – 11 kg, with a growing period between 10 and 17 weeks. The stocking density is much higher during the first phase due to the smaller size of the turkeys.

There are two main types of housing for turkeys. The first type is a closed, thermally insulated building with forced ventilation. Forced ventilation (negative pressure) is applied by fans and inlet vanes. An example of a closed forced ventilation structure is shown in Figure 3. The second type is an open house with open side walls and louvre-type curtains allowing for controlled natural ventilation. Natural ventilation is created via automatically controlled louvre-windows or wall-mounted inlet valves. Open houses are aligned at right angles to the prevailing wind direction and located in such a way as to be exposed to natural airflow. Additional ventilation is applied via ridge slots and gable openings. Gas heaters are used to provide heating. Closed buildings are typically used to house young turkeys in the first rearing period, and to rear the females in the finishing phase. For the finishing period, toms are more often reared in houses with open side walls and natural ventilation, which may also be fitted with outdoor free ranges (European Integrated Pollution Prevention and Control Bureau [EIPPCB], 2015)
2.2.1 Housing Factors

Housing for turkeys is designed to maintain specific conditions. Several factors must be controlled, particularly during the brooding period. Factors that are important for the indoor environment of the turkey housing generally are:

- Air temperature and humidity,
- Air composition and air velocity at bird height,
- Light intensity and duration,
- Dust concentration,
- Air quality, and
- Stocking density.

Adjustments are usually made by controlling the temperature, ventilation, and lighting. Minimum health standards and production levels enforce requirements on the indoor climate of poultry houses (EIPPCB, 2015).
2.2.1.1 Air temperature

During the brooding period turkey housing requires a constant temperature (32 – 34 °C), therefore heating is applied to the facility. Over time, as the turkeys grow, the indoor temperatures are gradually decreased. Heating is usually provided by space heaters, direct heating (e.g. infrared, gas/air heating, gas convectors, hot-air cannon), indirect heating (central heating of space, central heating of underfloor), and heat exchangers (EIPPCB, 2015). It is critical to maintain the correct temperature, as it has an effect on bird behaviour. If conditions inside are too warm, it can cause heat stress, the occurrence of pasty excreta on the cloacal area, frequent spreading of the wings, frequent wing flapping, and panting. Signs of low environmental temperature include feather ruffling, rigid posture, trembling, huddling, and piling on top of each other (Hybrid, 2013).

2.2.1.2 Ventilation

Poultry housing ventilation is dependent on the climatic conditions and the birds’ requirements. The objective of ventilation is to provide air circulation, which delivers fresh air and removes gaseous products, along with heat and moisture. This helps ensure suitable and livable conditions for the livestock. The facility typically can be designed to force the ventilation air stream across or longitudinally through the building, or from an open ridge in the roof downwards via fans below the cages.

For both forced and naturally ventilated systems, prevailing wind direction may be a contributing factor to the positioning of the building. For example, a certain building orientation may increase the required control of the ventilation while also reducing emissions to certain areas of the farm.

Ventilation is important for the birds’ health and will therefore affect production levels. Ventilation is used for maintaining the composition of the indoor air at the required levels. As an example, for turkey facilities, Ontario Ministry of Agriculture Food and
Rural Affairs (OMAFRA) set minimum requirements for environmental parameters that need to be ensured:

- NH$_3$ concentration not exceeding 25 ppm;
- CO$_2$ concentration not exceeding 5,000 ppm;
- indoor temperature, to be 21 - 22°C for the bird’s comfort;
- indoor average humidity, measured over 48 hours, to be within 55% - 65%.

2.2.1.3 Feeding

Feed and water are always provided throughout the barn so the birds may eat and drink freely. Feed management is entirely dependent on the type of production and the species of bird. Feed can be given in mash, crumbs, or pellet form. Most production birds are fed ad libitum. Hand feeding is still used in smaller operations, however in large production facilities, modernized feeding systems are used (see Figure 4) to reduce feed spillage, allow for accurate feeding, and to monitor feeding habits and patterns. Other common feeding systems include:

- chain feed conveyor,
- auger conveyor,
- feeding pans, and
- moving feed hopper.
2.2.1.4 Drinkers

All animals must have permanent access to a suitable water supply or be able to satisfy their fluid intake needs by other means (EIPPCB, 2015). For all poultry species, water must be available without restriction. Birds use water to regulate and control their body temperature. Water is used to support digestion of the feed as well (EIPPCB, 2015). The drinking water system is also used to provide micronutrients to birds in case of additional requirements. Design, proper maintenance, and control of the drinking system aim to provide sufficient water at all times and to prevent leakages and spillage thus reducing the wetting of the litter. There are several different drinking systems:

- high-capacity nipple drinkers (around 80–90 ml/min or higher);
- low-capacity nipple drinkers (around 30–50 ml/min);
• round (or bell) drinkers (Figure 5);
• water troughs (or cup drinkers).

The main advantage of a high capacity nipple drinker is that the bird quickly receives a proper amount of drinking water, however, there is a level of leakage associated with this system. Often to catch the leakage, little cups called drip cups are placed underneath. Nipple drinkers with a drip cup are the most economical in water consumption. Low-capacity nipple drinkers are not affected by leakage, but drinking takes longer with nipples than with bell drinkers (IPCC, 2015).

Figure 5 Example of Bell Drinker (Plassonlivestock.com, 2016)

2.2.1.5 Lighting

Poultry housing can receive lighting either by artificial or natural light. Bird activity can be directly affected by the choice of lighting and the length of the lighting period. In turkey rearing, lighting is particularly important during the first few days of rearing (1 – 7 days). Lighting is programmed to have an intensity of at least 10 lux (up to 50 lux) and two to three hours of total darkness (IPCC, 2015). Afterwards, the light intensity is reduced. Light schemes can vary with lighting lasting from 14 to 16 hours per day.
It is beneficial to give turkeys a dark period to reduce aggressiveness and improve overall performance (Hybrid, 2009). A typical lighting schedule can be seen in Figure 6.

*Figure 6 Turkey Lighting Program for Heavy Males (Hybrid, 2009)*
2.3 Manure Characterization

Poultry manure is full of nutrients and can be used for land application. This practice reduces or eliminates the cost of synthetic fertilizers used for crop growth. Typical turkey manure composition is summarized below in Table 2

*Table 2 Average Nutrients in Turkey Manure (Brown, 2013)*

<table>
<thead>
<tr>
<th></th>
<th>Dry Matter %</th>
<th>Total N (%)</th>
<th>NH₄-N (ppm)</th>
<th>NH₄-N (%)</th>
<th>P (%)</th>
<th>K (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Average Toms</strong></td>
<td>50.4</td>
<td>2.53</td>
<td>8,334</td>
<td>0.83</td>
<td>1.33</td>
<td>1.42</td>
</tr>
<tr>
<td><strong>Heavy Toms</strong></td>
<td>52.3</td>
<td>2.62</td>
<td>8,675</td>
<td>0.87</td>
<td>1.38</td>
<td>1.59</td>
</tr>
</tbody>
</table>

Manure characterization is a useful tool that can help predict CH₄ and NH₃ concentrations. This is done by performing a mass balance to determine the amount of nitrogen the turkeys are taking in and expelling. To achieve this, feed and litter weights need to be monitored, which directly relate the amount of nitrogen going in and out. An example of a nitrogen balance is displayed below in Figure 7. The numbers labelled (1) are measured values through feed going in, manure coming out, and measured ammonia from the system. The numbers labelled (2) are calculated based on the measured values.

*Figure 7 Example of Estimated Nitrogen Budget for Chicken Broiler (Guiziou, and Béline, 2005)*
2.3.1 Litter management

Management of turkey litter can affect the amount of NH$_3$ and GHG emissions generated during the production cycle. Management practices of the litter include: managing moisture content, different bedding materials, frequency of litter cleanout, monitoring litter build up, and use of additives to the litter. By managing and monitoring the manure and litter, turkey productions can greatly affect and reduce the amount of NH$_3$ and GHG emissions.

2.3.1.1 Bedding Material

Studies have been completed that show the effect of different bedding material in relation to NH$_3$ emissions. Van Harn et al. (2012) considered the effects of NH$_3$, PM$_{2.5}$, and PM$_{10}$ emissions from a chicken broiler house. The study included 2,260 broilers and was comprised of two production cycles lasting 35 days. Results of the study indicated ammonia emissions were 36%, 34% and 47% lower when silage maize was used as a bedding material over wood shavings, wheat straw, and rapeseed straw, respectively. It was concluded that silage maize may be a good alternative bedding to wood shavings and wheat straw in broiler houses. The reduction in emissions could be due from the fermentation of the silage maize.

2.3.1.2 Litter Removal

There has not been a thorough investigation of the effects of litter removal and emission of GHGs in turkeys. However, there is literature detailing the same principle with chickens, which can be used to develop an understanding of the factors and effects that could easily correlate to turkey production. Typically, the manure pack in a turkey facility is made up of two layers with the top layer being the manure cake, where the turkeys scratch and mix in their excreta. The top layer acts as cushion, and occasionally gets removed with a machine called a skimmer. The bottom layer of the manure pack often stays soft and “fresh”. Two studies (Liang et al., 2005; Nicholson et al., 2004) found that NH$_3$ emissions can be reduced by using manure belt systems,
where excreta are deposited onto belts positioned below cages and routinely operated to remove excreta and transport it to storage.

2.4 Ammonia

2.4.1 Ammonia Formation

Ammonia (NH$_3$) found in poultry facilities is not directly produced by the birds, but is a by-product of the poultry waste. The excreta coming from the turkeys contains unused nitrogen from their feed, as well as uric acid. NH$_3$ is formed as a result of these nitrogenous compounds going through microbial degradation. The undigested proteins and uric acid make up 25% to 34% and 60% to 75% of the all nitrogen in excreta, respectively (Groot Koerkamp, 1994). Both the undigested proteins and uric acid can generate ammonia through the enzyme urease, as described in the following chemical equations (Groot Koerkamp, 1994):

\[
\text{(Uric acid) } C_5H_4O_3N_4 + 1.5O_2 + 4H_2O \rightarrow 5CO_2 + 4NH_3
\]

Undigested Proteins $\rightarrow$ NH$_3$

Urease is an enzyme found in the animal feces, which catalyzes the hydrolysis of urea, forming ammonia. This conversion can occur very swiftly, often only requiring a few hours. Ammonium and ammonia can be produced from this conversion, but is dependent on pH. Ammonia generation requires a higher pH level and is less soluble in water, therefore is converted in a gaseous form (Gay & Knowlton, 2009). A simplified biochemical process for the conversion is as follows (Groot Koerkamp, 1994):
Both ammonium (NH$_4^+$) and ammonia can be produced from this conversion, depending on the pH of the litter substrate. Ammonia is emitted as a gas at higher pH levels (Gay & Knowlton, 2009). There are various conditions that are favourable for microbial growth, resulting in higher ammonia production. These conditions include:

- warm temperatures,
- higher moisture contents,
- a moderately basic pH in the range of 7.0-8.5, and
- the presence of organic matter.

The creation of ammonia from any litter management operation can be highly variable, depending on total ammonia concentration in the litter, temperature, pH, and storage time. This means that ammonia emissions are typically not consistent throughout the year and vary based on seasonality and regional climate factors (Espinoza, 2008).

2.4.2 Health and Environmental Effects

NH$_3$ that is emitted from agricultural operations can result in increased levels of particulate matter though the formation of secondary inorganic aerosols (Morse, 1995). Atmospheric NH$_3$ can also lead to surface water eutrophication which can produce unwanted algal growths (Gay & Knowlton, 2009).

High concentrations of ammonia are dangerous to poultry and human workers. A
short-term exposure limit of 35 ppm over a 15-minute period has been legislated by the Occupation Health and Safety Act (Ontario Ministry of Labour, 2015). Exposure to high levels of ammonia in air may be irritating to skin, eyes, throat, and lungs and cause coughing and burns. Lung damage and death may occur after exposure to very high concentrations of ammonia (Agency for Toxic Substances and Disease Registry, 2004). For turkeys, levels of ammonia higher than 25 ppm during brooding periods lead to reduced final body weights (Gay & Knowlton, 2009; Reece et al, 1980). Exposure to even low levels of ammonia can cause irritation to the lungs and eyes of poultry.

2.4.3 Sampling Methods

The EPA lists the three most commonly used techniques for continuously measuring ammonia in the air as: infrared laser spectroscopy, photoacoustic infrared, and chemiluminescence (US EPA, 2007). Chemiluminescence is the preferred US EPA method.

2.4.3.1 Infrared Laser Spectroscopy

Laser absorption spectroscopy is a powerful process of analysis for atmospheric trace gases with resolvable rotational vibrational absorption features, especially in the midinfrared region containing the stronger fundamental vibrational bands (Ellis et al., 2010). Infrared (IR) spectroscopy uses the ability of molecules to absorb frequencies that are distinguished by their structure. This method uses a pulsed quantum cascade laser with ammonia absorbing radiation at 967 cm⁻¹ (Ellis et al., 2010).

2.4.3.2 Photoacoustic Infrared Analyzer

Photoacoustic spectroscopy measures the effects of light absorption by solids, liquids, and gases by means of acoustic detection (Malkin and Cahen, 1979). For gas detection, the analyzer converts light absorbance to photoacoustic signals (PAS) and, in general, delivers better sensitivity than conventional infrared (IR) gas spectrometry. The IR light from the tungsten lamp is first modulated by a mechanical chopper and
then passed through a narrow-band optical filter to remove all wavelengths except for the “measuring wavelength” characteristic of the target gas (Li, Zhang, & Xin, 2015). In the measurement chamber, the target gas molecules become energized upon light absorption, and dissipate the absorbed energy in the form of heat. The chopper modulated pulsed light creates heat expansion and contraction of the sample. The sample temperature and pressure will vary because of this. The change in temperature and pressure creates acoustic-waves which decay as they move through the sample. The signal is recorded by microphones and converted into an electrical signal with is correlated to a gas concentration (Li, Zhang, & Xin, 2015).

2.4.3.3 Chemiluminescence

Chemiluminescence is the creation of light resulting from a chemical reaction. The process involves two chemicals reacting to create an excited intermediate, which degrades and releases a portion of its energy as photons to reach its ground state (Welsh, 2011). Chemiluminescence uses the light producing reaction of nitric oxide (NO) with ozone (O₃) as its basic principle. Specifically:

- The external pump draws a sample into the analyzer.
- It mixes with ozone, which is generated by the internal ozonator after the sample reaches the reaction chamber.
- The last chemical reaction below then takes place.

\[
\begin{align*}
NO_2 & \rightarrow NO \\
NH_3 & \rightarrow NO \\
NO + O_3 & \rightarrow NO_2 + O_2 + h\nu
\end{align*}
\]

This reaction produces a specific luminescence, where the intensity is proportionally related to the concentration of NO. Specifically, the light emission occurs when the electronically excited NO₂ molecules decay to lower energy states. The light emission is sensed by a photomultiplier tube, which in turn generates an electronic signal. A microcomputer then processes the signal and relates it into a NO concentration reading. Measuring NH₃ with a chemiluminescence analyzer first requires that all NH₃
is transformed to NO. This is achieved as the sample passes through an \( \text{NH}_3 \) scrubber, then through of a stainless-steel converter heated to approximately 750°C.

2.5 Carbon Dioxide

2.5.1 Generation Mechanisms

Carbon dioxide is formed through the normal combustion of fuel in brooder stoves and heaters, as well as through the respiration of the birds. Low ventilation rates, due to poor air mixing and distribution, can result in elevated levels and pockets of concentrated carbon dioxide which are a potential health hazard (OMAFRA, 2013).

\( \text{CO}_2 \) is also generated from turkey respiration, as well as transformations in the organic matter in livestock manure. In the litter substrate, the production of \( \text{CO}_2 \) is mainly from the oxidation of easily degradable carbon compounds and the rate of formation depends on the nature of the substrates, oxygen and moisture availability, and the activity of micro-organisms (Andersson, 1996).

2.5.2 Health and Environment Effects

Frame, Buckner, and Anderson (2010) determined that elevated carbon dioxide levels can negatively impact bird performance. Roundheart disease or spontaneous turkey cardiomyopathy (STC) has been linked to levels of carbon dioxide in excess of 2500 ppm (Frame et al., 2010). Excessive carbon dioxide concentrations can cause inactivity in birds, such as reduced feed intake and altered metabolism, and have a negative impact on gut health and overall flock performance (Hybrid, 2013).

Birds at all ages are affected by elevated levels of carbon dioxide; however, young birds show significant effects. High levels of carbon dioxide can cause the birds to become lethargic and inactive. They begin to huddle as their metabolism and feed intake reduces (Frame et al., 2010).
Exposure to excessive carbon dioxide can increase early bird mortality (V.L. Christensen et al., 1995). The study found that levels of 4000 ppm of carbon dioxide resulted in reduced thyroid activity, which led to decreased metabolism. When this happens, birds become lethargic, reducing their feed and water consumption. This can lead to poor gut development and an imbalance of gut microflora, leading to caecal destabilization and eventually enteritis. When caecal destabilization occurs, litter becomes wet and environmental conditions can deteriorate. This can lead to poor flock performance, including low weight, poor skeletal development and poor uniformity of the flock.

Exposure to 4000 ppm of carbon dioxide can also result in altered metabolism, depleted glycogen reserves, lowered liver glucose levels, and lowered blood oxygen levels. The study by Christensen et al., 1995 noted that all poults exposed to 4000 ppm of carbon dioxide fell asleep, indicating that carbon dioxide levels must be kept well below 4000 ppm. This is consistent with the findings of Frame et al. (2010).

2.5.3 Sampling Methods

The US EPA defines a method of continuous monitoring of CO$_2$ as the US EPA Method 3A Determination of Oxygen and Carbon Dioxide Concentrations in Emissions from Stationary Sources (US EPA, 1989). Although the EPA does not recommend a specific method, the guidelines in US EPA Method 7E Determination of Nitrogen Oxides Emissions from Stationary Sources (Instrumental Analyzer Procedure) should be followed for continuous monitoring.

The USA EPA Method 3A stipulates that the sampling equipment found in Method 6C - Determination of Sulfur Dioxide Emissions from Stationary Sources (Instrumental Analyzer Procedure) (US EPA, 2008) may be used for CO$_2$. Analyzers allowable under Method 6C include any instrument that uses ultraviolet, nondispersive infrared, or fluorescence as the detection principle to continuously measure CO$_2$ in the gas stream.
2.5.3.1 NDIR CO₂ Sensor

Nondispersive infrared (NDIR) is the most common type of sensor used to measure CO₂. An infrared lamp directs light at an infrared light detector through a ventilated tube. The light detector measures the amount of IR that reaches it. Any gas molecules with the same wavelength of the IR light will absorb the IR light only, while letting other wavelengths of light pass through. Next, the remaining light hits an optical filter that absorbs every wavelength of light except the exact wavelength absorbed by CO₂. Finally, an IR detector reads the amount of light that was not absorbed by the CO₂ molecules or the optical filter. The difference between the amount of light radiated by the IR lamp and the amount of IR light received by the detector is measured. The difference is proportional to the number of CO₂ molecules in the air inside the tube (CO₂ Meter, 2012). A schematic of a simplified NDIR is shown in Figure 9.

Figure 9 Diagram of NDIR (Co2meter.com, 2016)
2.6 Methane

2.6.1 Generation Mechanisms

Methane is a reaction product of the anaerobic bacterial decomposition of organic compounds present in feed and excreta. It is emitted as a by-product of enteric fermentation and also from the decomposition of manure under anaerobic conditions, increasing with the volatile solids content of the excreta (Fabbri et al., 2007). Enteric fermentation is a digestive process by which carbohydrates are broken down by microorganisms in the animal digestive tract (mainly in ruminants). CH$_4$ emissions from enteric fermentation are expected to be negligible for turkeys. Emissions are from manure management, related to a lack of oxygen in stored manure (Fabbri et al., 2007).

2.6.2 Health and Environmental Effects

Methane is a colourless and odourless, non-toxic, combustible gas therefore it is difficult to detect, even at increased levels (OMAF, 2013a). Gaseous methane is an asphyxiant, and is particularly hazardous if methane accumulates in an enclosed facility. In high concentrations, it may displace oxygen supply which can cause suffocation and loss of consciousness. Other effects include headaches, dizziness, weakness, nausea, vomiting, and loss of coordination. Methane can be generated from the digestive processes of domesticated livestock, which can be problematic for the animals if oxygen supply is displaced, therefore it is necessary to limit these health risks.

To reduce the risk of asphyxiation, poisoning, and even explosions, the Ontario Ministry of Labour, under the current Occupational Exposure Limits for Ontario Workplaces required under Regulation 833, has put the time weighted average limit (TWA) for all aliphatic hydrocarbon gases (C1-C4) at 1000 ppm. This is supported by both the National Institute for Occupational Safety and Health (NIOSH) and the
American Conference of Governmental Industrial Hygienists (ACGIH) which sets the 8-hour workday limit for humans at 1000 ppm.

Although Environment Canada does not classify methane as toxic, the Canadian Environment Protection Act (CEPA) 1999 has included methane on the Schedule 1 – List of Toxic Substances. Environment Canada also classifies it as a greenhouse gas (Environment Canada, 2013b). Methane, as a GHG, is contributing to rises in atmospheric temperature and climate change. Heat stress, drought, and changing weather patterns are major concerns related to the release of GHG and climate change. Although methane doesn’t linger in the atmosphere for as long as carbon dioxide (approximately a 10-year atmospheric half life) it has a CO$_2$ equivalent of 25 (IPCC, 2012), meaning it would require 25 times more CO$_2$ than methane to produce similar effects with regards to climate change.

2.6.3 Sampling Methods

The US EPA Methods 25A and 25B give guidelines for the monitoring and gas sampling of CH$_4$, namely (US EPA, 2002a). Flames ionization detection (FID) and non-dispersive infrared analyzers (NDIR) are associated with Methods 25A and 25B, respectively. Method 25A is used to determine total amount of volatile organic compounds (VOC), measured as total gaseous non-methane organics (TGNMO) and reported as carbon, in stationary source emissions (US EPA, 2002a). This method involves air passing through a heated sample line and a glass fiber filter eventually into an FID. Method 25B also draws air through both the heated sample line and glass filter before entering the NDIR (US EPA, 2002b).

2.6.3.1 Flame Ionization Detector (FID)

FID measurement of methane and non-methane hydrocarbons is based on gas chromatography. It operates by having the sample drawn into an eight port, rotary valve with two positions. The two positions are “inject” and “back-flush” (Figure 11). The valve is used to bring the sample into the analyzer, while also controlling the
gasses through the chromatograph separation column. Between analyses or operating on standby mode, the rotary valve is left in the backflush position. When in this position, the sample gas is continuously pulled through the sampling loop which is a coil of empty tubing. Once analysis begins, the valve switches positions to inject, which connects the carrier inlet to the sample loop, which introduces the sample gas to a flow of non-reactive carrier gas.

![Figure 10 8-Port Rotary Valve, Backflush and Inject Positions (Thermo Scientific, 2003)](image)

The carrier gas (nitrogen) moves the sample away from the continuous loop and into the injection end of the separation column. From there, the sample flows through the column with all the different components moving at varied rates. This is due to differences in physical and chemical properties. The separation of components is decided by chemical properties include boiling point, gas flow rate, polarity, as well as column temperature and length. Methane has a small molecular weight and high volatility; therefore, it flows quicker than the other organics making it the first leave the column.

The methane then moves back through the rotary valve and into the FID. The methane produces a voltage signal which is measured by the FID. The signal is transformed into a concentration based on a comparison to a previously produced signal, from a known calibration gas. After the methane peak is detected, the rotary valve switches back to the backflush position and at this point the direction of the
carrier stream is reversed. Due to the reversal of the carrier flow, the non-methane hydrocarbons (NMHC) are backflushed out and carried to the FID for measurement. The process of measurement is the same as methane, where the NMHCs reach the FID creating a signal that is compared against a known value. With the addition of the data logger to continuously monitor the FID signal, the output creates a chromatogram which will depict one peak for methane and another for the NMHCs. A typical chromatogram obtained from the analysis can be seen in Figure 11.

![Figure 11 Gas chromatograph from FID (Thermo Electron Corporation, 2003)](image)

2.6.3.2 Non-Dispersive Infrared (NDIR) Analyzer

A non-dispersive infrared analyzer also incorporates a gas chromatography system. For the NDIR technique, fixed narrow-band filters are utilized with separate IR detectors to detect a few gas absorption lines across a restricted wavelength range. These analyzers use the information on how molecules absorb radiation and how the infrared spectrum of molecules can be processed to give details on the structure of
the molecule. Infrared radiation from two infrared sources, pass through adjacent sample and reference cells and into corresponding detector cells. A sample of the gas is contained in the sample cell while a non-reactive gas is held in the reference cell and the pure methane gas is contained in the detector cells. There are two identical detector cells, which follow the reference and sample cells. They communicate through a differential capacitance manometer, which measures small pressure differences between the two detector cells (Crawley, 2008). The methane gas absorbs radiation and thus depletes the infrared intensities. This results in a lower energy reading on the sample detector cell and reduces the pressure rise compared to the reference side detector cell. This noted pressure difference is related to the concentration of absorbing gas in the sample cell, which is then determined using a calibration graph. A schematic of the NDIR process is displayed below in Figure 12
2.7 Emission Factors

There are few studies published for turkey production and subsequent emissions (Wood and Van Heyst 2016) (Table 3). A study by Li et al. (2011) sampled emissions from two turkey production facilities and sampled for 10 and 16 months each, in which data collection occurred only during the grow-out period. Both facilities used litter that was built up, as this is common practice for poultry production in North America. To sample the emissions, a photoacoustic analyzer was used. Fan runtimes and rotational speed was also monitored. The Fan Assessment Numeration System
(FANS) unit was used to create operational points.

Although some studies exist, information regarding turkey emissions is still limited. Since built up litter is common practice in grow-out operations, there is the potential for a large amount of NH$_3$ to be released. More information and data needs to be collected to fully understand the effect turkey production has on the environment and to further test practices that mitigate emissions.

*Table 3* Summary of NH$_3$ EF and ER literature review for Turkey Production

<table>
<thead>
<tr>
<th>Type of Production</th>
<th>Country</th>
<th>Study</th>
<th>EF (g/d/AU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turkey</td>
<td>Europe</td>
<td>Van Der Hoek (1998)</td>
<td>113</td>
</tr>
<tr>
<td>Turkey</td>
<td>Europe</td>
<td>Asman (2001)</td>
<td>126</td>
</tr>
<tr>
<td>Turkey</td>
<td>Canada</td>
<td>Navaratnasamy and Feddes (2004)</td>
<td>2.448 ± 0.176 (g/day/bird)</td>
</tr>
<tr>
<td>Turkey (grow out)</td>
<td>United States</td>
<td>Gay et al. (2005)</td>
<td>120.5</td>
</tr>
<tr>
<td>Turkey (brooder)</td>
<td>United States</td>
<td>Gay et al. (2005)</td>
<td>7.2</td>
</tr>
<tr>
<td>Turkey</td>
<td>United States</td>
<td>Li et al., (2009)</td>
<td>1.52 (g/d/bird)</td>
</tr>
<tr>
<td>Turkey</td>
<td>United States</td>
<td>Li et al., (2011)</td>
<td>73.6 ± 53</td>
</tr>
<tr>
<td>Turkey Untreated</td>
<td>Canada</td>
<td>Wood et al (2015)</td>
<td>203±185</td>
</tr>
<tr>
<td>Turkey Treated</td>
<td>Canada</td>
<td>Wood et al (2015)</td>
<td>134±139</td>
</tr>
</tbody>
</table>
Table 4 IPCC Summary of reported air emission levels from poultry houses (IPCC, 2015)

<table>
<thead>
<tr>
<th>Type of Poultry</th>
<th>NH₃</th>
<th>CH₄</th>
<th>N₂O</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>kg per bird place per year</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Laying hens - enriched cage systems</td>
<td>0.01-0.15</td>
<td>0.034-0.078</td>
<td>0.017-0.023</td>
</tr>
<tr>
<td>Laying hens - Non-cage systems</td>
<td>0.019-0.36</td>
<td>0.078-0.2</td>
<td>0.002-0.180</td>
</tr>
<tr>
<td>Pullets (cage and not cage systems)</td>
<td>0.014-0.21</td>
<td>NI</td>
<td>NI</td>
</tr>
<tr>
<td>Broilers</td>
<td>0.004-0.18</td>
<td>0.004-0.006 (²)</td>
<td>0.009 (²) - 0.032</td>
</tr>
<tr>
<td>Broiler Breeders</td>
<td>0.025-0.58</td>
<td>NI</td>
<td>NI</td>
</tr>
<tr>
<td>Turkeys (female) Whole Period</td>
<td>0.045-0.387</td>
<td>NI</td>
<td>0.015 (²)</td>
</tr>
<tr>
<td>Turkeys (male) Whole Period</td>
<td>0.138-0.68</td>
<td>NI</td>
<td>NI</td>
</tr>
<tr>
<td>Ducks</td>
<td>0.05-0.29</td>
<td>NI</td>
<td>0.015 (²)</td>
</tr>
<tr>
<td>Guinea fowl (²)</td>
<td>0.8</td>
<td>NI</td>
<td>0.015</td>
</tr>
</tbody>
</table>

(²) Source [43, COM 2003]
NI – No Information

There is limited literature detailing the EFs of all pollutants from turkey production. Although there is data on ammonia from previous studies; CO₂, CH₄ and N₂O have limited data referencing EFs. An in-situ study (Guiziou et al, 2005) from a chicken broiler house in France examined ammonia and greenhouse gas emissions. The study concluded that there were no emissions of N₂O and CH₄ observed during the growth of the broiler or above the litter at the end of the experiment. During the rearing period, the differences between the concentrations of CH₄ and N₂O measured outside and inside the concrete floor room, using the infrared gas analyser, were always lower than the detection level (5 ppm). According to these results, N₂O and CH₄ emissions from broiler houses seem to be very low. Such figures are comparable with results obtained by other authors (Groot Koerkamp and Ueng, 1997; Neser et al., 1997; Macke and Van Den Weghe, 1997). This consistent finding of low emission rates for N₂O and CH₄ could explain the limited available literature on GHG emissions from turkey production.
3.0 Instrumentation

The equipment used for the experimental procedure is described in this chapter. All of the equipment used in this study was calibrated as set by the manufacturer and met the safety standards of the associated manufacturer.

3.1 Continuous Gas Measurement System

3.1.1 Gas Analyzers

The equipment used for sampling CO\textsubscript{2}, CH\textsubscript{4}, NH\textsubscript{3}, consisted of:

- Thermo Electron Corporation Model 55C Direct Methane, Non-Methane Hydrocarbon analyzer (NMHC) (55C),
- Thermo Electron Corporation Model 17i Chemiluminescence NH\textsubscript{3} analyzer (17i), and
- SD800: CO\textsubscript{2}/Humidity/Temperature Datalogger.

The 55C uses a FID in order to record levels of CH\textsubscript{4} and non-CH\textsubscript{4} hydrocarbons (Thermo Electron Corporation, 2003b). The 17i employs a chemiluminescence reaction with O\textsubscript{3} to measure levels of NO, NO\textsubscript{2}, and NH\textsubscript{3} (Thermo Electron Corporation, 2014). The SD800 is a maintenance free dual wavelength NDIR (non-dispersive infrared) CO\textsubscript{2} sensor. The analyzers (Figure 13) are summarized in Table 5, along with the gasses they detect and corresponding detection limits, sample rates, and logging interval times.
Table 5 Gas Analyzer Specifications

<table>
<thead>
<tr>
<th>Model</th>
<th>Gas Species</th>
<th>Detection Limit</th>
<th>Sample Rate (L/min)</th>
<th>Logging Interval (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>17i</td>
<td>NO</td>
<td>1 ppb</td>
<td>0.6</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>NO2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>NH3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>55c</td>
<td>CH4</td>
<td>20 ppb</td>
<td>0.5</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>NMHC</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SD800</td>
<td>CO2</td>
<td>1 ppm</td>
<td>-</td>
<td>5</td>
</tr>
</tbody>
</table>
The air stream supply to the 17i and 55C gas analyzers was through chemically inactive Teflon tubing with an outer diameter of 0.625 cm (¼") and inner diameter of 0.47 cm (3/16"). An additional requirement for the 55C was a compressor pump which worked to remove any moisture within the air stream entering the analyzer. This is necessary as this area housed the flame for the FID. The model of compressor pump was GAST model #1HAB-11T-M10. Similarly, the 17i requires an external moisture scrubber. The 17i employs a mixture of Drierite and silica beads to remove moisture.

![Image of Thermo Scientific 17i, GAST compression pump, Thermo Scientific 55C, SD800 CO₂ Monitor]

Figure 13 Clockwise from top left: Thermo Scientific 17i, GAST compression pump, Thermo Scientific 55C, SD800 CO₂ Monitor

3.1.2 Sample Lines and Pump
To supply sample air to the Model 17i NH$_3$ analyzer, a diaphragm pump was included in the sample line. The pump used was a KNF UN035.1.2 TTP (Figure 14) (KNF Laboratories, 2013). The flow rate for the specific pump operating at atmospheric conditions was 20 L/min. The inclusion of the pump provided necessary flow to the analyzers, with remaining air exhausted through an atmospheric dump line. The relatively dry conditions in the room negated the need for heated sample lines. The solenoid valve’s output line for the Model 55C Methane and NMHC analyzer was connected to a CleanAir Engineering, Inc. single head diaphragm 26 L/min sampling pump Model ADI R-Series 9769 TI (Figure 15) (CleanAir Engineering, Inc., 2014).
3.1.3 Solenoid

Two solenoids were deployed to alternate between three sample lines that included a sample line from Chamber One, Chamber Two, and ambient air from the room. The solenoids were connected to a Campbell Scientific, Inc. CR1000 Micrologger (Figure 16) (Campbell Scientific (Canada) Corp., 2016). The output of solenoid two was connected to the 17i and 55C for ammonia and methane sampling.
3.2 Chambers

Two Plexiglas chambers with dimensions of 1.06 m x 0.610 m x 0.853 m (3.5 ft. x 2 ft. x 2.8 ft.) were used to house the birds for the daily trials. The chambers were equipped with drinkers and feeders, and had an exhaust point located approximately 2/3 of the way up one side of the chamber wall. The opposite side of the chamber had nine 0.635 cm (¼ in.) diameter holes to allow ambient air into the chamber. The holes were placed near the bottom of the chamber to cause airflow directly across the litter and create better air mixing with the exhaust point (see Figure 17).

![Figure 17 Plexiglas Chamber with Inlets and Exhaust](image)

3.3 Temperature and Relative Humidity

For continuous monitoring of the temperature and relative humidity (RH) within the two chambers, two Tiny Tag Plus 2 TGP-4500 loggers were used (Gemini Data Loggers, 2016) (refer to Figure 18 for a picture). The TGP-4500 monitors temperatures from -25 °C to +85 °C and RH from 0% to 100%. The accuracies associated with temperature and relatively humidity are ±0.01°C and ±3.0%, respectively. The TGP-4500 includes a 0.01°C and 0.03% resolution for temperature and RH. Due to the robust nature of the logger, it required minimal maintenance and has a storage capacity of 32,000 readings. The coated RH sensor offers good
resistance to moisture and condensation, and the IP68 water-proof rating and the high accuracy make the TGP-4500 a very reliable and accurate logger.

Figure 18 Tiny Tag TGP-4500 RH and Temperature logger (geminidataloggers.com, 2016)

3.4 Room Parameter Monitoring

Two Extech SD-800 CO₂/Humidity/Temperature Datalogger (refer to Figure 13) were used to continuously monitor temperature and RH in the room. The Extech SD-800 monitors temperatures from 0 °C to 50 °C and a RH from 10% to 90%. The accuracy associated with temperature and relatively humidity is ±0.8°C and ±4.0%, respectively. The TGP-4500 includes a 0.1°C and 0.1% resolution for both temperature and RH. The SD 800-has selectable data sampling rates of: 5, 10, 30, 60, 120, 300, and 600 seconds.

3.5 Exhaust System

Due to the low ventilation rate of the chamber compared to a turkey facility, an manometer and iris damper system was utilized to measure discrete flow measurements related to the ventilation of each chamber.
3.5.1 Iris Damper

The exhaust rates were determined by two Continental Fans 10 cm (4 in.) IRIS Dampers (Figure 19) as they produce rapid, accurate, and reliable measurements of exhaust. Since the ventilation unit was comprised of computer fans, standard exhaust collection procedures used for large fans (such as a FANS unit or balometer) could not be used.

The design of the damper and the inclusion of an input and output point allow for controlled measurement at a single station. The IRIS damper is comprised of a casing, damper blades, an adjustment or regulating nut, an airflow adjustment chart, and airflow taps. Blades and casing are manufactured from either galvanized (IRIS) or 316 stainless steel (IRIS-S). The remaining components are made from high strength plastics (Continental Fan, 2016).

The operating principle is that the IRIS damper represents a resistance to airflow in a duct which translates to a pressure drop. The damper has two taps, before and after the fins. The resulting pressure drop across the fins can be determine through airflow in the taps and correlated to an exhaust rate. The damper blades can be opened and closed with the regulating nut and can be set to certain positions (1-7). The chosen position has a unique ‘k’ factor that defines the performance curves at different damper settings.

![Figure 19 IRIS Damper Principle (Continental Fans, 2016)](image-url)
The ‘k’ factor, along with the pressure difference, are used in Equation 1 to calculate the resulting exhaust flow rate, where \( q \) is flow rate in cfm, \( k \) is a unitless constant of proportionality, and \( p_m \) is the measured pressure drop recorded in inches of water (inAq) which has a conversion of 1 inAq = 248.84 pascals @ 15°C.

\[
q = k \sqrt{\Delta p_m} \quad (1)
\]

Figure 20 depicts an iris damper, the blue tab holds the regulating nut, which when rotated opens or closes the fins to a desired position. The difference in pressure is inversely proportional to the size of the opening. The two red plastic columns extending from the damper are the tabs used to attached the manometer to in and outflow. As mentioned, one tab is positioned before the blades and the corresponding tab is after. The manometer is attached to the two tabs to get an accurate reading of both the flowrate and pressure drop across the iris damper blades.

Figure 20 Iris Damper

3.5.2 Manometer

To determine the pressure drop across the iris damper, a Dwyer Instruments Model UHH2 Universal Handheld Test Instrument was used. The Model UHH2 is an Android® based handheld unit that benefits from the functionality and versatility of
the Mobile Meter® Software App. The manometer is made up of three parts: the UHH2, which is the main component for data logging and user interface; the WDPM probe, which measures the pressure; and UHH-BTG, which converts the WDPM probe signals into Bluetooth signals which are then picked up the UHH2 and logged. The UHH2 can log continuously for the set duration, with logs every second and a one second response time. The two barbed connections (3.18 mm (1/8 in.)) on the WDPM (refer to Figure 21) were attached to the two taps on the IRIS damper to determine the pressure drop.

![Figure 21 Model WDPM probe (Dwyer Instruments, 2016)](image)

The Dwyer model UHH2 is a multifunctional tool that can quickly and accurately measure pressure, air velocity, air flow, temperature, and humidity. Each IRIS damper contains two airflow taps (pressure ports) and an Airflow Adjustment Chart. By connecting a pressure gauge to the taps of the damper, the pressure drop across the damper blades is measured. To obtain an indirect measurement of air flow based on pressure drop across the damper, Continental Fans® provides a selection curve (Figure 22). The observed average pressure difference is located on the y axis. To determine the air flow, follow the point horizontally until intersected by a red line that corresponds with the position of the damper (in this case position 4).
Figure 22 Iris Damper Selection Curve
4. Study Facilities

4.1 Facilities Description

During the assessment, the turkeys were housed in the ANNU building on the University of Guelph Campus. The housing areas were maintained and coordinated by Animal Biosciences staff who performed daily checks. The staff provided feed, water, wood shavings, and cleaned the pens. For the duration of the experiment, two separate rooms in the basement of the ANNU building at the University of Guelph were used. ANNU room 055 was used for the experimental chambers, where all the sampling was conducted. ANNU room 050 was used as a central penning station to house the 19 turkeys for the period of testing. Room 050 had a barrier to keep the high efficiency turkeys and low efficiency birds apart. The separation was necessary for several reasons:

- Accurate measurement of difference in feed intake for high efficiency vs low efficiency turkeys,
- Ability to collect separate manure samples for each efficiency type, and
- Limiting social aggression due to size difference (i.e. pecking order).

The barrier created two separate penning areas, approximately 4.57 m by 3.05 m (15 ft. by 10 ft.). Each area included one pressurized, drinking bell and gravity fed feeder (Figure 23).

General upkeep of the penning room included providing feed, checking water levels, litter removal, and observing bird behavior. Room 050 was equipped with a light timer which provided light from 6:00 – 20:00, with the 14-hour lighting schedule reflective of industry standards. Feed was added when levels were low in the feeders and water levels were checked to make sure automated bell drinkers were operating correctly. Litter removal was completed every 3 – 4 days and new wood shavings were laid down. Additionally, daily checks included observations of behavioral changes as an indicator for sickness. This would include lameness, not rising from the ground when
people enter the room, and for toms, a decrease in vocalisation when greater than 18 weeks. The turkeys were provided with lighting, heating, and ventilation for the duration of the experiment. The environment enrichment provisions were within industry standards to relay the most realistic results. These included regulating temperatures to 21 - 22 °C, having a stocking density (1.39 bird m²/bird), and a lighting intensity 10x greater than dark period.

![Figure 23 Penning Area for High Efficiency Turkeys](image)

**Figure 23 Penning Area for High Efficiency Turkeys**

4.2 Feeding and Drinking Regime for Penning Room

Control of feed intake was critical to develop an understanding of the biological parameters in the turkey breed lines. Generating an FCR requires adequate information on the total intake of feed per each group of turkeys. For each group, feed bags were weighed, and then distributed. Feed levels were checked daily and replenished from the bags by the staff, as needed.
Drinking levels were replenished daily, however exact measurements were not taken for water intake. In the penning room, water was distributed through a pressurized, gravitational bell drinker system. One bell drinker is required per a hundred turkeys, therefore one per ten was adequate in the penning room.

4.3 Chamber

The monitoring of gaseous emissions for the study was conducted within two chambers placed in room 056. The two chambers were identical in material and size. The chambers were 1.06 m x 0.610 m x 0.853 m (3.5 ft. x 2 ft. x 2.8 ft.) and made entirely of Plexiglas. The wall joints of the chambers were sealed with silica gel. All edges of the environmental chambers were completely sealed shut except for one half, in which a plastic door hinge (seen in Figure 27) was applied to allow the top to be opened. This provided an access point to replenish feed/water and place and remove the turkeys daily.

To create a tight seal when the door is closed, 3M 4317 Urethane Foam Tape was applied to the chamber where the door opened. On the side of the chamber where the water trough was, a 10 cm (4 in.) hole was drilled to connect the ventilation system to the chamber. An ABS flange was placed with adhesive inside the hole to allow the ventilation duct to be easily attached to the chamber. Inside the chamber, metal meshing was bolted to the flange to discourage pecking of the ventilation duct from the turkeys (refer to Figure 24).
4.4 Feeding and Drinking Regime for Chamber

Feed inside the chambers were monitored and recorded daily. Each chamber was equipped with one feeder and one drinking station (Figure 27 Chamber Set Up). The mass of the feed going in and the mass of the food remaining after eight hours was weighed and recorded for each day of the trial.

In the chambers, the water was supplied by a trough that was cleaned out daily. It held approximately 1 L per day for each chamber. Bedding in the chambers was weighed before being placed in the chamber and weighed again when removed, this was done to estimate the amount of waste excreted. The litter was cleaned out every morning, and it was at this time when the litter would be weighed to determine how much excreta had been deposited.
4.5 Ventilation

The ventilation of the chambers were built with three major pieces: aluminium duct, IRIS damper, and the fan box. The duct was 2.4 m (8 ft.) long with a 12.7 cm (5 in.) diameter. It was composed of flexible aluminum ducting, which ran from the chamber to the fan box. The final piece of duct connected the fan box to the building's ventilation inside the chamber room. The system was built to prevent contamination from the gasses generated inside the chamber to the ambient air in the room. The IRIS damper was included in the system to measure exhaust rate. The damper was placed between the chamber and the fan box due to the requirement of air being pulled through it. The full network is shown in Figure 25.

![Ventilation Network](image)

*Figure 25 Ventilation Network*
The fan box housed the exhaust fan. The box was made of plywood and was 12.7 cm x 12.7 cm (5 in. x 5 in.). On both ends of the box, a 10 cm (4 in.) hole was drilled to allow air flow through. The holes were the same size to keep constant flow and avoid back pressure. Both outside walls of the box were attached with an ABS flange to attach the duct and complete the system. Figure 26 shows a top view looking into the fan box. The black outer ring is the ABS flange, which is attached to the fan box. The flange has an extended lip which is used to attach aluminum duct. The ventilation fan is a Noctua NF-A14 FLX 140 mm Case Computer Fan. The NF-A14-FLX was selected for its high air flow rate and relatively small size. The fan was placed inside of the fan box and a small hole was cut into the side of the box, which allowed the electrical wires to be accessed.

Figure 26 Aerial View of Fan Box (Left) Depiction of Fan Used Inside (Right)

4.6 Turkey Grouping

The turkeys were divided up into two different groups, high efficiency and low efficiency, based on their genetic line. An imperative part of the study was to keep both groups held in equitable housing with the same feeding, drinking, lighting, and ventilation regime. It was important to maintain similar living conditions to prohibit environmental factors from affecting the emission factors. Therefore, the groups were penned in the same room, with a divider in the middle. The groups were penned
together to reduce stress, and daily checks were performed to ensure there were no
behavioural changes.

The groups were identified using coloured spray dyes. A large spot was sprayed on
the breast, green for low efficiency and yellow for high. All turkeys were tagged with a
kurl-lock style wing tag, with consecutive numbers for individual identification. Low
efficiencies were tagged 301 - 309 and high efficiency 310 - 319.

Two turkeys were euthanized during the trial and one bird was taken off the trial but
permitted to remain in the pen. The first euthanasia occurred before the
commencement of the trial. A broken wing occurred during transport from the
production facility to the study site. During the trial, birds 306 and 303 both had wings
broken. Bird 306 was euthanized, while bird 303 remained with the other turkeys, but
was removed from the trial. In summary, the high efficiency turkeys began and ended
with 10 birds, while the low efficiency turkeys began with 9 birds and finished with 7
birds remaining in the trial.
5. Methodology

The sampling methods and analysis for gases, PM, feed, urine, fecal matter, and exhaust rates are described in this section. Quality assurance and control are also explained to maintain consistent and reliable data.

5.1 Experimental Design

The campaign began on 04/18/16 and was completed on 05/16/16. Parameters of the study were not changed during the four-week campaign. Emissions were compared between two groups of turkeys. Included in the study were ten turkeys designated as having high efficiency and nine birds with low efficiency traits. The initial experimental plan designated ten turkeys per group; however, one bird from the low efficiency group broke a wing during transportation and was euthanized before the start of the trial. In order to begin experimentation involving live animals, an Animal Utilization Protocol (AUP) was completed (Appendix D), and approved by the Animal Care Committee (ACC). Due to this, there was a limitation set on the experimental design. The turkeys could only be monitored on an eight-hour per day basis. Therefore, the turkeys would be monitored from 8:30 - 16:30. This timeframe was selected to assure that staff from the Animal Biosciences would be on site if any issues occurred.

To obtain emission results, a sample line was placed in each chamber as well as in the middle of the room. The three lines were alternatingly sampled using solenoid valves. This was done to gain a representative sample of overall contaminant concentrations within the chambers and to achieve a baseline representation of the gases present in the facility room. The solenoid valves, which were controlled by a CR1000X Micrologger, would alternate between the three sample lines every 20 minutes. Sample air would be drawn from the environmental chambers and Room 055 into the analyzers located directly inside the facility room. Sample intervals for the three lines were set at 20 minutes, with air samples being drawn into the analyzers and recorded every five minutes.
Two randomly selected birds of each efficiency birds were monitored. The fours birds were in the chambers for the full eight-hour cycle. Monitoring occurred every day from 8:30 to 16:30 inside the environmental chambers. Litter would be built up during day and remain over night to assess GHG generation from microbial activity. Litter would be cleaned out every morning, to avoid confounding the data and remove uncertainty over the contributing factors for gaseous emissions. This is not typical of management practices, as litter is not replaced daily.

The two groups followed the same sampling protocol, and housing conditions were identical. Therefore, the FCRs of the birds would be the only factor that was different across the groups. Feed and manure were also weighed, and samples were taken during the campaign to perform overall nitrogen balances relating both the input (feed) and output (excreta) of the turkeys.

5.2 Methane, Ammonia, and Carbon Dioxide Sampling

5.2.1 Monitoring Setup

Three sample lines were used to sample ammonia and methane in the environmental chamber. Two sample lines monitored the conditions in separate Plexiglas environmental chambers, and a third line sampled the ambient air in Room 055. These three lines were operated by two alternating solenoid valves. The solenoid valves, controlled by a CR1000 Micrologger, would alternate between chamber 1, chamber 2, and the room on a 20-minute rotational cycle. Every five minutes, sample air would be drawn into the 17i ammonia and 55C methane analyzers. Sample inlets were placed two thirds of the way up from the ground to ensure a full and representative sample. The sampling line reached the midpoint of the chamber and was open to the natural flow path of air (the bulk concentrations of contaminants within the chamber).

The carbon dioxide monitor was placed in the chamber and, unlike ammonia and
methane, the analyzer did not draw a sample of the chamber air in, therefore did not require the use of solenoid valves or sample lines. The placement of the CO₂ monitor, TinyTag, and inlet can be seen in Figure 27. The air flowed over the CO₂ analyzer with it logging a concentration every five minutes.

![Figure 27 Chamber Set Up](image)

Due to the alternation of the sample lines, it was important to calculate the time it took for a sample to be drawn into the analyzers. This calculation would identify the timing of air samples being drawn in and determine if there was sample contamination. Knowing the sample rate and diameter of the line, equation (2) was used to determine the velocity of the sample using the continuity law, where \( Q \) is the airflow rate, \( A \) is the cross-sectional area of the pipe and \( v \) is the velocity.

\[
\Delta t = \frac{L}{v} = \frac{LA}{Q} \quad (2)
\]

The length of tube (m) was divided by the velocity (m/s) to determine the amount of time for a subsample of air to travel from the chamber across the sample tube and
into the analyzer. The length of tube was 5 m, which estimates a sample time of 19 s. Because of this time delay, there is evidence that sample contamination would occur, therefore the first sample of every 20-minute switch (i.e. the first sample of chamber 2 after sampling chamber 1) was removed from the data to avoid line contamination. Because of this, chamber 1, chamber 2, and the room would collect three data points every hour, at the 0:10, 0:15, and 0:20 intervals.

5.3 Sampling Room with Environmental Chambers

The environmental chamber room was used to conduct all monitoring and data collection, except for fecal collection which was collected in the penning room. The two environmental chambers were set up side by side to reduce separation stress in the turkeys, as they are a highly social species. Both chambers were connected to the same vent which exhausts all the air out of the room. All monitoring equipment was housed in the same room. This allowed for easy maintenance and calibration. The room (Figure 28) included the two chambers, all analyzers, and their respective calibration gases. Figure 28 depicts a running trial with two high efficiency (left chamber) and low efficiency (right chamber) turkeys.
Before the start of study, all analyzers underwent any suggested or required maintenance as advised by their manufacturers. The manufacturers recommended that full maintenance be completed once a year and/or more if needed. The analyzers were checked daily for any issues. For the 17i and 55c a diagnostics menu would display information regarding the operation of the analyzers. The main diagnostics readings were reported for:

- Voltages,
- Temperature,
- Pressure, and
- Flow.

If any of the values for the listed diagnostic parameters were outside of operational range, a flag notification would appear on the main screen. This allowed for easy maintenance and narrowed down troubleshooting to specific parts that were in need of replacement.
Calibration for all sampling equipment was performed at the beginning of the study and little maintenance was required thereafter. The analyzers underwent frequent calibration to avoid drift and bias. The required calibration gases are summarized in Table 6. The frequency of calibration differed between the analyzers, with the 17i analyzer requiring weekly calibration and the 55C analyzer requiring daily calibration.

Table 6 List of Support Gases

<table>
<thead>
<tr>
<th>Component</th>
<th>Concentration (ppm)</th>
<th>Functionality</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-Grade Nitrogen</td>
<td>-</td>
<td>Calibration (17i)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Carrier Gas (55C)</td>
</tr>
<tr>
<td>Nitric Oxide (NO)</td>
<td>16.2</td>
<td>Calibration (17i)</td>
</tr>
<tr>
<td>Nitrogen Dioxide (NO₂)</td>
<td>4.7</td>
<td>Calibration (17i)</td>
</tr>
<tr>
<td>Ammonia (NH₃)</td>
<td>25.1</td>
<td>Calibration (17i)</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>-</td>
<td>Fuel Source (55C)</td>
</tr>
<tr>
<td>Propane/Methane</td>
<td>100/99</td>
<td>Calibration (55C)</td>
</tr>
</tbody>
</table>

5.4.1 Model 55C CH₄ Analyzer

The model 55C requires a two-point calibration that utilizes a zero gas and a span gas. Due to the operational parameters of the analyzer (air flow, fuel flow, temperatures, etc.) it is not possible to do a permanent calibration. Therefore, frequent calibration is required. The span gas consists of a propane/methane mixture that is made up of 100/99 ppm respectively. The zero gas is ambient air that will pass through a scrubbing tower of activated carbon, then into a second tower filled with a Purafil® material. Between the two towers that make up the zero-air generator, the gas is cleaned so that there is no interference.

5.4.2 Chemiluminescence NH₃ Analyzer

The 17i Chemiluminescence NH₃ analyzer works using four discrete single-point
calibrations and known concentrations for the three gases it measures (NO, NO₂, and NH₃) as well as a zero gas (high-grade N₂) (see Table 6).

The most consistently required maintenance was changing the scrubber that contained both Drierite™ (calcium sulfate) and silica beads when their point of saturation reached. This was done as needed (approximately every 3-4 days) in order for the zero-air source to be adequately used for dilution, calibration, and gas phase titration (Thermo Electron Corporation, 2004).

5.5 Feed Sampling

Feed samples of approximately 500 g were collected in a plastic bag halfway through the campaign. The samples were brought directly to Agriculture & Food Laboratory (AFL) unit of the Laboratory Services Division at the University of Guelph. The samples were used to produce a total nitrogen amount for the feed sample for the nitrogen mass balance. AFL completed nitrogen determination by combustion. Nitrogen freed by combustion at high temperature in pure oxygen is measured by thermal conductivity detection and converted to equivalent protein. The final output of percent nitrogen is derived from Equation (3).

\[
\% \text{ N (Dry Matter basis)} = \frac{N \text{ (from analyzer output)} \text{ Lab Dry Matter}}{100} (3)
\]

5.6 Feces Analysis

Wet feces samples were collected directly from the penning room (where all birds were housed). The samples were collected from the floor and placed in plastic sample bags, and transported immediately to the AFL laboratories. To determine dry matter percentage of the sample, drying ovens (105 °C and 500 °C) were used. A humidity controlled oven was used for mineral content (P, K, Ca, Mg, and Na). Finally, the Kjeldhal method was used to assess total N and the standard saturated paste method for pH.
5.7 Bird Weight

To determine the FCR of the two groups, body weight was measured at the beginning, midpoint, and end. To track healthy growth and derive a growth chart, it was important to monitor the weight of the turkeys going into the chamber each day. Daily weight of the birds was used to calculate the emission factors, the process of which is highlighted below. To weigh the birds, they were placed into a plastic tote and weighed on an automatic livestock scale, which weighed the turkeys to within 0.1 g. The livestock scale was calibrated before the trial and every two weeks after using known weights. All 19 birds were weighed on 04/17/16, 05/03/16, and 05/16/16. Additionally, the four birds (two high, two low) used in the trial on a particular day were weighed at the end of the day to estimate daily growth for the genetic lines.

5.8 Feed Weight

Measurement of feed intake was critical to develop an understanding of the biological parameters of each genetic line. Generating a FCR requires adequate information on the total intake of feed per group of turkeys. Therefore, for each group (high efficiency, low efficiency), feed bags were weighed, dated, then distributed. Additionally, the weight of the chamber feed was measured once in the morning and again at the end of the day to determine how much feed was eaten during the day. The amount of feed consumed from the chambers was tallied and added to the value of feed consumed from penning room bags; this determined the total amount of feed consumed by each group during the four weeks.

5.9 Data Analysis

5.9.1 Emission Factor Calculations

To evaluate the emission factors in terms of mass emitted (g/day/AU and g/hr/bird), the data needed to be transformed. The first conversion is from the raw concentration of ppm or ppb into a g/m³ form. The concentrations are recorded on a five-minute
sampling interval. Due to the nature of the fixed ventilation, the ventilation was consistent throughout the campaign and independent of weather and temperature. Therefore, every five-minute sampling point was multiplied by the same ventilation rate (m$^3$/h). Multiplying the concentration by the exhaust rate provides a total output for the gas analyzed (g/hr). The last step in the process was to determine the gas output on a per animal basis. The g/hr value was divided by the summed weight of the turkeys in the chamber and multiplied by the animal unit (AU) which is representative of 500 kg of live mass. The EF was calculated using Equation 4.

$$EF = \frac{(C_1 - C_0)Q}{M} \times \left(\frac{500 \text{ kg}}{AU}\right) \quad (4)$$

Where: EF = Emission Factor (mass/time)
C$_1$ = Concentration in Chamber (mass/volume)
C$_0$ = Concentration in Room (mass/volume)
Q = Exhaust Rate (volume/time)
M = Mass of Turkey in Chamber (mass)

5.9.2 Statistical Analysis

Statistical analysis was completed using Minitab. To analyze the means of the high and low efficiency EFs and determine statistical significance of the difference, a two-sided z-test was used. The z-test was chosen over a t-test due to the large sample size. For the z-test, normality is a constraint; therefore, a unique box-cox power transform value was used on each of the data sets to satisfy the normal criteria.

A z-test also assumes independence; however, this is not the case for this data. The data has observations taken close together; they are not independent and are serially correlated. Time series analysis had to be used to adjust for the correlated observations. In this analysis, the dependence between observations is a serial correlation (Ramsey & Schafer, 2002). The time series analysis test takes into account autocorrelation within the data and the statistical value outputted is a z-test value.
To begin adjusting for correlation, the $c_1$ and $c_0$ values must be determined using the equations found below. The equation for $c_1$ (equation 5) is the summation of the residuals (res) of a given time (t). The residuals are the deviation from the estimated mean at a given t. $c_0$ (equation 6) is summation of res squared at a given t. Both values are divided by the degrees of freedom (df) which is given by the total number of samples minus 1.

$$c_1 = \frac{1}{n-1} \sum_{t=2}^{n} res_t \times res_{t-1}$$  \hspace{1cm} (5)$$

$$c_0 = \frac{1}{n-1} \sum_{t=1}^{n} res_t^2$$  \hspace{1cm} (6)$$

These auto covariance estimates are then pooled based on the two independent time series (i.e. the two genetic lines), as given by:

$$c_{1, pooled} = \frac{(df_1 \times c_{1,1}) + (df_2 \times c_{1,2})}{df_1 + df_2}$$  \hspace{1cm} (7)$$

$$c_{0, pooled} = \frac{(df_1 \times c_{0,1}) + (df_2 \times c_{0,2})}{df_1 + df_2}$$  \hspace{1cm} (8)$$

The pooled autocovariance estimates are then divided by each other to determine the adjustment factor ($r_1$) (equation 9). The adjustment factor then helps to determine the standard error of the difference in averages ($SE(\bar{X}_1 - \bar{X}_2)$), which is based on the sample standard deviations of the time series $s_1$ and $s_2$. The standard error in this method is essentially the same as when evaluating two independent samples (i.e. not time series-based), but with an adjustment factor. Each of these factors are estimated through the equations listed below.

$$r_1 = \frac{c_{1, pooled}}{c_{0, pooled}}$$  \hspace{1cm} (9)$$

$$s_p = \frac{df_1 \times s_1^2 + df_2 \times s_2^2}{df_1 + df_2}$$  \hspace{1cm} (10)$$

$$SE(\bar{X}_1 - \bar{X}_2) = \sqrt{\frac{1 + r_1}{1 - r_1}} \times s_p \times \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}$$  \hspace{1cm} (11)$$
Following the adjusted standard error estimation, the equality of means is assessed through a population $z$-statistic (Ramsey & Schafer, 2002) where the null hypothesis of equal means is evaluated at the standard 95% confidence level (i.e. $z_{0.95,n}$).
6 Results

Results and discussion provided below reflect the two aspects of this project. The first is corresponding to the calculation of the feed conversion ratio. These results are found in the first two sections of Chapter 6, where total feed and total weight gained are discussed. Further in Chapter 6, the results of the gaseous emissions are discussed and correlated to the two genetic lines on the basis of their differing FCRs. Using the concentration of the gasses and the ventilation rates measured in both environmental chambers, emission factors for CH₄, NH₃, CO₂ were transformed into units of g/hr/AU, as well as g/hr/bird.

6.1 Bird Weight and Growth

Tracking the growth of the birds was integral to understanding the FCR and how they could correlate to a difference in emissions. The birds began the trials at the age 15 weeks, equivalent to 105 days. The body weights of all the birds were measured three separate times: at the beginning of the trial, halfway through the trial, and on the last day. The body weight of the birds selected to be housed in the chamber was measured each day after eight hours in the chamber. Figure 29 compares the difference in growth between the low efficiency turkeys and the high efficiency turkeys. Evidently, low efficiency birds experienced a stronger linear relationship, but grew at a slower rate compared to high efficiency birds.

Again, noting discrepancies in the birds, the high efficiency group began the trial 3.5 kg heavier (Figure 30). The difference coefficient of determination for the high efficiency can be attributed to the use of bird 316 in the trial. This particular high efficiency bird began the trial 2 kg lighter than the average for group and grew at a reduced rate in comparison. Bird 316 was selected for the chambers on days 10, 12, 19 and 27. All four days corresponded to points below the trend line. The mass for each bird in the trial is shown in Figure 31. All birds were weighed on three separate occasions: beginning of the trial (04/17/16), in the middle (05/03/16), and at the end of the trial (05/16/16).
Figure 32 shows a typical turkey growth curve from day 0 to 120, a typical production cycle. Highlighted in the red box is the curve trend from approximately day 110 onward. The noted general trend is linear for that duration compared to the overall exponential curve. This was added as a comparison to the growth curve for the birds in this campaign.

![Average Bird Mass Gained (kg/day)](image)

*Figure 29 Average Mass Gained*
Figure 30 Average Weight of Turkey in Chamber

Figure 31 Individual Turkey Weights
6.2 Feed Conversion Ratio

The FCR corresponds to the amount of feed that is converted into mass gains. The FCR calculation for big production facilities is difficult to calculate accurately, mainly because of the difficulty of obtaining a precise value for feed intake. However, it is still a valuable tool to obtain a representative estimate of how much feed (kg) is required to gain 1 kg of mass. There are only two parameters required to calculate the FCR, the total amount of feed and the amount of mass gained over the period.

The FCR (Equation 12), was estimated for the two groups of turkeys using the parameters listed in Table 7. As indicated, the high efficiency group required approximately 2 kg of feed for every 1 kg of mass gained while the low efficiency group required slightly more than 3 kg of feed for the same mass gain. Both of these values are within the range of literature values for typical turkey FCRs. This is a significant difference in FCRs ($p = 0.027$). Since there is an established difference in FCRs across the two groups, the difference in EFs can be assessed to determine which group emits a higher quantity of pollutants.
During the trial, the low efficiency turkeys tended to be more aggressive and resistant to handling, which may have led to lower amount of feed intake while in the chamber. During the trial, bird 306 from the low efficiency group was euthanized due to a broken wing, and was omitted from the FCR calculation.

\[
FCR = \frac{Total \ Weight \ of \ Feed \ (kg)}{Estimated \ Weight \ Gained \ (kg)} \tag{12}
\]

<table>
<thead>
<tr>
<th>Feed (kg)</th>
<th>High</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chamber</td>
<td>7.65</td>
<td>6.14</td>
</tr>
<tr>
<td>Penning Room</td>
<td>147</td>
<td>147</td>
</tr>
<tr>
<td>Total Feed (kg)</td>
<td>155</td>
<td>156</td>
</tr>
<tr>
<td>Weight Gained (kg)</td>
<td>77.3</td>
<td>43.9</td>
</tr>
<tr>
<td>FCR</td>
<td>2.00</td>
<td>3.14</td>
</tr>
</tbody>
</table>

**Table 7 FCR Table**

6.3 Temperature

6.3.1 Temperature Inside Chamber

Temperature was monitored inside both chambers, during the sampling campaign, as well as outside. The inside temperatures are shown in Figure 33 and Figure 34 compares both inside and outside temperatures. Observing the graph a few trends appear. One such trend refers to difference in temperatures while the birds are inside the chamber compared to when they are not. While the birds were inside the chamber, there were spikes in the temperature readings as they give off heat.

Taking a closer look at the maxima, it appears that the high efficiency birds produced more heat for the duration inside the chamber, which can be attributed to the size difference between the high and low efficiency birds. At any point throughout the campaign, the study birds in the high efficiency group were approximately 4-5 kg heavier than their low efficiency counterparts, adding up to 10 kg more mass inside the chamber. The average temperature for the eight hours the birds were inside the
chambers was 23.9 °C for high and low efficiencies. Comparatively, when the birds were not inside the chambers, the average temperatures were 22.9 °C and 23.2 °C for high and low efficiencies, respectively. The most likely cause for the difference in temperatures would be the proximity of the low efficiency chamber to the test analyzers system, as depicted in Figure 28. The low efficiency chamber (on the right) would have been impacted from the equipment and pumps giving off residual heat. However, the decrease in temperature is not large and the temperatures within the chambers were similar.

Between 04/30/16 – 05/01/16, there was an electrical shut down at the research facility. Because of this shut down, all analyzers and equipment in the testing room were turned off at 16:30 on 04/30/16 and restarted at 8:30 on 05/02/16. This resulted in a complete shutdown of heating and ventilation which shows a slight drop in temperature that can be observed in Figure 33. At approximately the midway point of the trial, the temperature dropped over 1° C, after maintaining a relatively stable temperature on the days before and after the shutdown.

At the end of the graph there is a significant drop off in temperature from 05/12/16 to the end of the campaign. There were no alterations to the procedure, and no major differences made inside the room or chambers. The significant drop was the result of the research facility switching from winter to summer temperature regime and the cooling system being turned on.
Figure 33 Inside of Chamber Measured Temperature
Looking at the average hourly temperature in Figure 35, similar trends to Figure 33 and Figure 34 are apparent. During the time when the turkeys were in the penning room and not in the chambers, the low efficiency chamber was slightly warmer than the high efficiency chamber. This is seen again in Figure 34 comparing all the sensor readings; the two tiny tags from inside the chamber as well as the CO2 sensor reading outside of the chamber. The high efficiency temperature readings were highly consistent during the drops in temperatures when the birds were not in the chambers. However, the low efficiency temperature readings from outside the chamber were slightly higher than the readings from inside. The temperature gauge would be even closer to the analyzer system, suggesting that it is in fact the heat source contributing
to the differences between the temperature in the low and high efficiency chambers. It is important to monitor temperature changes as temperature does have an effect on ammonia generation. Ammonia emission factors have a positive linear trend with temperature (Trudell, 2014). At higher temperatures, ammonia production increases, however the difference in temperature between the two chambers were relatively negligible.

Figure 35 Average Temperature Inside Chambers
6.4 Relative Humidity

Similar to the results found for temperature, relative humidity seems to be related to body weight of the birds. Figure 36 depicts the relative humidity inside each of the chambers during the campaign. There is high number of minor but rapid changes in RH, clustering the data. This grouping of data points can be observed every day of the campaign except for April 30th and May 1st. On these dates the birds were not inside the chambers, therefore activities that would affect RH such as manure deposits and water spillage did not occur. The average RH for the genetic lines was reasonably similar at 27.5 ± 10.1% for the low efficiency group, and 28.7 ± 10.8% for the high efficiency.

![Figure 36 Measured Relative Humidity Comparison](image-url)
6.5 Manure Results

Manure drop samples, consisting of litter (excreta and bedding), were collected five times each for both high efficiency and low efficiency. Samples were taken from both groups on the same day. A sample would be collected for the high efficiency group, and then sample for the low efficiency group would be taken immediately after. The manure samples were taken from the penning room floor, and attempts were made to ensure a higher portion of fresh samples was taken. Most of the collection occurred where the birds clustered, which was typically around the feed station. Manure samples were taken to Agri-food Labs for analysis, similar to the feed analysis. The results for the low and high efficiency group manure samples along with the parameters tested are detailed in Table 8 and Table 9.

Table 8 Manure Sample Summary for Low Efficiency

<table>
<thead>
<tr>
<th>Sample</th>
<th>Total N (% wet)</th>
<th>Dry Matter (%)</th>
<th>Ammonium - N (mg/kg/wet)</th>
<th>Phosphorus (% wet)</th>
<th>pH</th>
<th>Potassium (wet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample 1</td>
<td>1.44</td>
<td>39.5</td>
<td>1030</td>
<td>0.416</td>
<td>6.5</td>
<td>0.626</td>
</tr>
<tr>
<td>(April 24th)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sample 2</td>
<td>1.18</td>
<td>34.7</td>
<td>970</td>
<td>0.370</td>
<td>8.1</td>
<td>0.489</td>
</tr>
<tr>
<td>(May 2nd)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sample 3</td>
<td>1.39</td>
<td>34.3</td>
<td>975</td>
<td>0.344</td>
<td>6.2</td>
<td>0.499</td>
</tr>
<tr>
<td>(May 5th)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sample 4</td>
<td>1.43</td>
<td>29.7</td>
<td>867</td>
<td>0.500</td>
<td>6.9</td>
<td>0.504</td>
</tr>
<tr>
<td>(May 12th)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sample 5</td>
<td>1.2</td>
<td>34.9</td>
<td>984</td>
<td>0.482</td>
<td>6.6</td>
<td>0.527</td>
</tr>
<tr>
<td>(May 16th)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>1.33 ± 0.12/8</td>
<td>34.6 ± 3.47</td>
<td>965 ± 59.8</td>
<td>0.422 ± 0.068</td>
<td>6.86 ± 0.737</td>
<td>0.529 ± 0.056</td>
</tr>
</tbody>
</table>
Table 9 Manure Sample Summary for High Efficiency

<table>
<thead>
<tr>
<th>Sample</th>
<th>Total N (% wet)</th>
<th>Dry Matter (%)</th>
<th>Ammonium - N (mg/kg/wet)</th>
<th>Phosphorus (% wet)</th>
<th>pH</th>
<th>Potassium (% wet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample 1 (April 24th)</td>
<td>0.999</td>
<td>33</td>
<td>633</td>
<td>0.322</td>
<td>6.9</td>
<td>0.44</td>
</tr>
<tr>
<td>Sample 2 (May 2nd)</td>
<td>1.03</td>
<td>32</td>
<td>706</td>
<td>0.424</td>
<td>7.2</td>
<td>0.462</td>
</tr>
<tr>
<td>Sample 3 (May 5th)</td>
<td>1.18</td>
<td>30.5</td>
<td>878</td>
<td>0.412</td>
<td>6.2</td>
<td>0.456</td>
</tr>
<tr>
<td>Sample 4 (May 12th)</td>
<td>1.22</td>
<td>26.9</td>
<td>1160</td>
<td>0.431</td>
<td>6.4</td>
<td>0.476</td>
</tr>
<tr>
<td>Sample 5 (May 16th)</td>
<td>1.22</td>
<td>29.7</td>
<td>929</td>
<td>0.464</td>
<td>6.5</td>
<td>0.539</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>1.12 ± 0.107</strong></td>
<td><strong>30.4 ± 2.35</strong></td>
<td><strong>861 ± 206</strong></td>
<td><strong>0.411 ± 0.0531</strong></td>
<td><strong>6.64 ± 0.404</strong></td>
<td><strong>0.475 ± 0.0382</strong></td>
</tr>
</tbody>
</table>

The key factor for this study was the amount of nitrogen present in the manure. This is directly related to the FCR differences, as well as the ammonia production. The important principle considered for FCR is the feed intake and what the bird can do with the nutrients in the feed. The higher efficiency turkey will have a lower FCR value, which means it takes less feed to gain mass. Consequently, this means the turkey used more of the nutrients in the feed, thus excreting fewer nutrients in the manure.

Both groups were fed using the same feed and housed under similar conditions, therefore any difference in manure composition is assumed to be a direct result of the biological breakdown of the nitrogen in the birds’ gut, due to genetic selections. As seen in Table 8 and Table 9, total nitrogen is found on average to be at a higher percentage in the low efficiency group’s manure ($p = 0.032$). This combined with higher levels of ammonium nitrate, and higher pH can provide conditions that better favour ammonia volatilization.
The dry matter indicates that the low efficiency group had consistently dryer litter than high efficiency group but at a slightly more basic pH. However, comparing 6.86 average pH to 6.64 is a moderately low difference ($p = 0.580$). However, formation of NH$_3$ is influenced by the pH of the litter and a slight increase of pH can produce more NH$_3$. Ammonia can increase up to an order of magnitude for every unit of pH that exceeds 6.0 (Follett, 1995). The ammonium – N (mg/kg/wet) varied considerably across the two groups, however the average amount for the low efficiency group was higher than the high efficiency group. This could play a key role in ammonia volatilization occurring from the litter.

6.6 Ventilation

During the testing campaign, the forced ventilation rate was not set up to be mechanically controlled. Large scale facilities will alter the ventilation rate mechanically to maintain required levels of temperature, relative humidity, and concentration of gases. The testing for this experiment was completed in an environmentally controlled room, therefore there was no need to alter the ventilation rate. This means that the exhaust rate was not dependent on any outside factor and was “fixed” at a constant rate for the entirety of the campaign.

To calculate the ventilation rate for the chambers, an iris damper was used (see Chapter 3 for a full description). The summazation of pressure differences for the exhaust collections is depicted in Figure 37, where the average pressure differences in the exhaust were 0.57 inAq (141.83 Pa) and 0.68 inAq (169.21 Pa) for the high efficiency and the low efficiency groups, respectively. Based on the selection curve, the exhaust rates were estimated at 122.5 m$^3$/h and 115.2 m$^3$/h (66 cfm and 73 cfm) for high efficiency and low efficiency groups, respectively. The exhaust rate could not be continuously monitored, therefore data was collected separately. However, ventilation rate was evaluated every day to ensure stability, specifically that it was operating within ± 5% of the initial ventilation rate.

The reason for the discrepancy in the pressure drops could be related to different
positioning of the exhaust lines. As both exhaust lines for the two chambers are connected to the main exhaust of the room, the height and the distance in relation to the centre of the room exhaust could contribute to differences in pressure. The two chamber exhaust lines were created from aluminum duct and had a path of 0.914 m (3 ft.), any slight discrepancy of the path would alter the pressure resistance due to the relation of height and pressure. Because the two fan boxes have a small difference in areas, the pressure across will be different. To summarize, due to mechanical and operational aspects of the fans, slight differences in the makeup of the system would contribute to differences in pressure.

Figure 37 Pressure Difference Across Iris Dampers
6.7 Emission Results

In this section, CO$_2$, CH$_4$, and NH$_3$ are discussed as a concentration (mass per volume basis) and as an emission factor (mass per time per animal unit basis). The respective stacked graphs for each pollutant contain a body weight graph to compare values. The graphs are all in the same magnitude with the exception of NH$_3$ concentration, which is given as ppb rather than ppm.

The individual pollutants produced from each genetic line are compared against each other, the high efficiency v. low efficiency groups. Each pollutant is shown for the high group and for the low group individually, with one graph comparing the two groups on an emission factor basis. All pollutants are displayed as independent to each other. Additionally, average hourly emissions will be presented for all three pollutants produced by birds of the two genetic lines.

In section 6.7, the results of the gaseous emissions are discussed and correlated to the two genetic lines on the basis of their differing FCRs. Using the concentration data measured in both environmental chambers and the corresponding ventilation rates, emission factors for CH$_4$, NH$_3$, and CO$_2$ were developed in units of g/hr/AU and g/hr/bird. Each pollutant has a summarized table listing averages and standard deviations for concentration, emission rate, and emission factor.

The relationships between the emissions from the high and low efficiency groups are explained in depth, with a conclusion provided in Chapter 7.
6.7.1 Carbon Dioxide

6.7.1.1 High and Low Efficiency Results

The stacked graphs depicting the CO$_2$, concentrations, body weight, and emission factors for the high efficiency group for the whole campaign are given in Figure 38. During the campaign, there was a mechanical shutdown of the research building which resulted in a data gap from 04/29/16 to 05/02/16. For body weights, there were four days, including the two shutdown days, where body weights were not taken. However, interpolated weights were calculated based on the growth curve for the individual birds that would have been used on that particular day.

To calculate the concentration of CO$_2$ in the room, the level in the chamber was subtracted by a baseline reading of CO$_2$ taken from room 055. The baseline readings were taken before and after the trial. The baseline CO$_2$ value of the room was 398 ppm, an average taken from several different times. This was substantiated by atmospheric CO$_2$ concentrations taken from literature, which show a concentration of 400 ppm of CO$_2$ in the atmosphere (Earth System Research Laboratory, 2016). Thus, all the “drops” in the data equate to approximately 0 ppm, which denotes the times the turkeys were not in the chambers. To get an accurate depiction of the amount of CO$_2$ present in the chamber in relation to the birds, data points exceeding 800 ppm were removed from the data set. These were noted as incidents that occurred during placement of the birds into the chambers or attaching feed and drinkers. It is assumed that during these times I exhaled directly on the analyzer, causing sample contamination. For the high efficiency group, 141 out of 6,624 or 2.13% of data points were removed and for low efficiency 126 out 6671 or 1.88% were removed.

The general trend is consistent local maxima and minima recorded every day throughout the campaign. The local maxima occur during the eight hours the birds are in the chambers. It can be seen in both stacked graphs that the concentrations of CO$_2$ emitted were reasonably consistent throughout the trial. For the high efficiency
group, the body weight had a significant effect on the CO₂ concentrations for the day. There are four days in which bird 316 was used for the trial. This particular bird weighed significantly less than the average for the high efficiency group. The four days where the bird was in the trial is easily detectable in Figure 38, as the combined body weight of the bird’s drops below the average trend. The days where bird 316 was used in the trial correlated directly to an increase in the EF.

There is an interesting trend observed in both genetic lines, but it appears more prominent for the high efficiency turkeys. While concentrations remain stable (no up or down trend), the EFs trend downwards as the sampling period extends. This is the effect on including body weight into the model. When calculating the EFs, the concentration in mg/hr are divided by the body weight of the turkeys in the chambers. Although the turkeys in the high efficiency genetic line are emitting CO₂ at a consistent concentration, the EF is being reduced by every iteration of weight gain.

As stated in the literature review, the most common CO₂ generation mechanisms would be through the normal combustion of fuel in brooder stoves and heaters, as well as through the respiration of the birds. In the current campaign, there was no external heating required; therefore, the CO₂ levels displayed below are a direct result of the respiration of the birds. Due to the configuration of the chambers, the CO₂ monitors were placed approximately at bird head level, near the drinking station. Thus, when birds were standing or drinking, they would be exhaling near or directly on the sensor. Therefore, the placement of the analyzer could be responsible for several spikes in the CO₂ that go beyond the average peaks (the cluster of values at the peak which create the blackened area).

Similarly, the stacked graphs giving the CO₂ concentrations, body weight, and emission factors for the low efficiency group for the whole campaign are given in Figure 39. There was an equipment failure that occurred between 04/23/16 - 04/25/16. The analyzer for the low efficiency group lost power; it was quickly restored to an operational status, however data recorded for the days noted was corrupted and irretrievable.
The low efficiency group generated similar trends as the high efficiency group, with low points equating to 0 ppm concentrations when the birds were not in the chamber. The body weights for all birds in the low efficiency group were more consistent compared to the group average than the high efficiency group, however there were still days in which the total body weight was lower than the general trend. As seen with the high efficiency group, there were decreases in the average CO\textsubscript{2} concentrations on those stated days. This links body weight to the amount of CO\textsubscript{2} being generated. There also appears to be a slight upwards trend in the CO\textsubscript{2} emission factors as the campaign moves forward. This trend is particularly evident across the first gap in data. Based on the data provided, it could be suggested that body weight is a factor in the generation of CO\textsubscript{2} from a bird level.
Figure 38 High Efficiency Group Carbon Dioxide Concentrations, Body Weight, and Emission Factors
Figure 39 Low Efficiency Group Carbon Dioxide Concentrations, Body Weight, and Emission Factors
6.7.1.2 Comparison Carbon Dioxide Emissions

Figure 40 compares the results between the high efficiency and low efficiency CO$_2$ levels. The average concentrations of CO$_2$ were found to be 512 (± 160) ppm and 434 (± 145) ppm for the high efficient line and low efficient line, respectively. There was a 16.1% difference ($p = 0.343$) between the groups. The emission factors are lower for the high efficiency group compared to the low efficiency at 4.67x10$^4$ (± 1.59x10$^4$) g/day/AU and 6.54x10$^4$ (± 2.19x10$^4$) g/day/AU respectively, which demonstrates a drop of 33.2% ($p < 0.0001$). Comparing the trends previously discussed, this appears to adhere to principle that a bigger bird will exhale more CO$_2$. Interestingly, in cases where the difference in combined body weights in the separate chambers decrease, the difference in CO$_2$ concentration decreases as well. It is difficult to tell in Figure 40, however on days where the combined high efficiency weight is lower than the trend, the cluster of average values for concentrations drops lower.

The connection to body weight is very evident in Figure 40, as although both genetic lines emit CO$_2$ in approximately equal concentrations (top graph) the EFs are drastically lower. This is especially evident in the latter half of the trial. It also important to note why calculating an emission factor gives more information that simply looking at the concentrations. If concentrations are solely observed, it can be noted that there isn’t a large difference between the two genetic lines, i.e. they both emit approximately equal parts of CO$_2$. By calculating the emission factor, it can be stated that the high efficiency genetic line emits less CO$_2$ per kg of product. In terms of numbers, 500 kg of the low efficiency genetic line will emit 33.2% more CO$_2$ than the high efficiency line.
<table>
<thead>
<tr>
<th></th>
<th>High</th>
<th>Low</th>
<th>Difference (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentration (ppm)</td>
<td>512 ± 160</td>
<td>434 ± 145</td>
<td>16.1</td>
</tr>
<tr>
<td>Emission Rate (mg/h)</td>
<td>1.06x10^5</td>
<td>± 1.03x10^5</td>
<td>± 3.09</td>
</tr>
<tr>
<td></td>
<td>3.33x10^4</td>
<td>3.44x10^4</td>
<td></td>
</tr>
<tr>
<td>Emission Rate (kg/head/year)</td>
<td>465 ± 146</td>
<td>451 ± 151</td>
<td>3.09</td>
</tr>
<tr>
<td>Emission Factor (g/day/AU)</td>
<td>4.67x10^4</td>
<td>± 6.54x10^4</td>
<td>± 33.2</td>
</tr>
<tr>
<td></td>
<td>1.59x10^4</td>
<td>2.19x10^4</td>
<td></td>
</tr>
</tbody>
</table>
Figure 40 Carbon Dioxide Emissions with Genetic Line Comparison
6.7.1.3 Carbon Dioxide Average Hourly Emissions

The emission concentrations for CO$_2$ follow a diurnal pattern dependent on whether or not the birds were in the chamber. Figure 41 indicates that when the birds are in the chamber, there were significantly higher levels of carbon dioxide. Figure 41 and Figure 42 represent the average hourly EF for high and low efficiency genetic lines, respectively. The dashed box represents the time in which the turkeys were monitored in the chamber.

As previously stated, the high efficiency birds produced CO$_2$ at a higher magnitude throughout the campaign. Looking at Figure 41, there was a slight increase in temperature at 11:00 which supports the hypothesis of increase bird activity (i.e. drinking water). Conversely, the CO$_2$ emission factor for the high efficiency birds was relatively constant at 50,000 g/day/AU. For the low efficiency bird, there is some deviation in the hourly average emission. There is an increase occurring from 9:00 to 12:00. This could be excessive panting due to stress of being moved to the chambers. The low efficiency genetic line birds never acclimatised to the routine and were more active, showing signs of distress after being handled. This could explain the decrease after 12:00, as they settle in after eating and typically they would begin to lie down.
Figure 41 Average Hourly CO₂ Emission High for High Efficiency
Figure 42 Average Hourly CO₂ Emission High for Low Efficiency
6.7.2 Methane Results

6.7.2.1 High and Low Efficiency Results

The methane data gathered during the campaign was at an elevated level compared against literature values for both turkey emissions of methane and atmospheric levels of methane. Comparing the raw methane concentrations in Figure 43, the elevated levels of methane can be observed. Typical levels of atmospheric methane are recorded at approximately 4 ppm. However, as noted in Figure 43, methane levels were considerably above that range, averaging 22 ppm.

To troubleshoot the problem, the 55c methane analyzer underwent several diagnostics, including recalibration, a direct sampling of zero air, and being directly connected to the methane/propane calibration mixture. All tests indicated that the analyzer was outputting accurate results. The analyzer correctly measured 0 ppm of \( \text{CH}_4 \) when directly sampling from \( \text{N}_2 \) gas cylinder, and correctly measured 99/100 ppm for \( \text{CH}_4 \) and NHMC when directly sampling from the calibration cylinder. Therefore, it was established that the analyzer was reading accurately above and below the expected value of \( \text{CH}_4 \) present in ambient air. Thus, the source of excess \( \text{CH}_4 \) was due to a leak in the room.

The experimental setup was transferred to an alternate room in the same facility. However, once the analyzers were turned on and calibrated, methane was still reading higher than expected values. Due to AUP limitations, available space, and scheduling, the decision was made to continue the experiment. The ambient methane levels in the room were recorded every hour as a baseline.

As previously mentioned, the ambient air outside the chamber was measured for 20 minutes every hour, using the same methodology for the chambers. The results of this testing are shown in Figure 43. This figure suggests that across the two chambers and in the room, there was a minimal difference in the methane levels.
However, when comparing both groups with the methane subtracted from the baseline reading, small differences emerge.

![Methane Concentration Graph](image)

*Figure 43 Methane Concentrations with Ambient Room Sample*

Similar to the carbon dioxide results, this section includes stacked graphs representing concentration, body weights, and emission factors for methane of both high and low efficiency. These graphs are shown in Figure 44 and Figure 45, respectively. The gaps in the data represent the mechanical shut down periods. Turkeys do not have a rumen; thus, they do not produce methane through enteric fermentation, a process responsible for higher methane emissions. Therefore, much of the methane emissions came from the excreta breakdown in the litter substrate. These emissions were generated by excreta deposited into the chamber and can be affected by temperature and moisture content.

Because the methane was reading at higher than expected levels, the ambient measurements were subtracted from the concentration inside the chamber. The result gave a significant number of negative values. Those negative values were assumed to be zero. Because there was a significant amount of ‘zero’ values, the
standard deviation is larger than the mean for methane emissions. As a result, no real conclusion can be made and the data is not significantly significant.

Statistical analysis was still performed on the data to compare the two genetic lines; the data underwent a Box-cox transform of ln+1 to normalize the data. A z-test was used to determine a statistical difference in the genetic lines’ emission factors. This returned a value of $p = 0.00113$, determining they are statistically different. However, due to the skewing of data by the zero values, the data does not provide enough information to state that the difference in methane emissions from two genetic lines are significant.

The stacked graphs in Figure 44 and Figure 45 show the chamber concentrations for the high and low efficiency groups respectively ($p = 0.291$). The top graph for both groups shows the concentration inside the chamber after subtracting the ambient concentration in the room. The room concentration was averaged over the 20 minutes, based off three sample times. As previously stated, the first data point in every series was removed to eliminate errors in the data created by line saturation, which occurs due to the sample flowrate into the analyzers. The first data point for every switch between chamber and room will be influenced by the previous source. Therefore, every hour each of Chamber 1, Chamber 2, and the ambient room record four data points, of which the last three were used to calculate the average concentration.

The methane results appear to be unaffected by the body weights when assessing both genetic lines. This is different to the results observed with carbon dioxide. This limited relationship would be caused by the generation mechanisms of methane. Methane emissions in poultry are related to the excreta deposits inside the chambers.
Figure 44 High Efficiency Group Methane Concentrations, Body Weight and Emission Factors
6.7.2.2 Methane Comparison Results

Figure 46 and Table 11 both indicate that the low efficiency group generated more methane than the high efficiency group, if observed through EF. In the comparison table, it can be observed that the high efficiency group recorded higher values of ppm of methane, generating 6.43% more. The rise in percent difference from a negative difference of 6.43% at ppm level to a positive difference of 40.1% at emission factor (g/day/AU) is attributed to the difference in generation of GHG per kg of turkey.

This study focuses on FCR as a factor affecting EFs. Therefore, body weight is an important factor to observe, particularly to the EFs. Table 11 indicates that body weight had a large impact on the emission factors for both groups, this is a trend also seen in the CO\textsubscript{2} emissions. This is because EF is calculated on an animal unit basis, where the emissions are correlated on g per day per AU basis. The animal unit is a representative of 500 kg of animal; therefore the EF is calculated based on the weight of the turkeys in the chamber scaled to 500 kg. Once BW is attributed, the low efficiency group generates methane at a higher level than the high efficiency group. Essentially, the EF would dictate that if a room contained 500 kg of low efficiency turkeys, it would emit 40.1% more methane than a room containing 500 kg of high efficiency turkeys.

The moisture content of the manure may have caused the high efficiency bird’s higher methane concentrations (ppm). Referring to Table 8 and Table 9, the average percentage of dry matter was 34.6\% \pm 3.47 for low efficiency and 30.42\% \pm 2.35 for high efficiency. This, in addition to the results obtained from Figure 36 where the high efficiency groups chamber was consistently higher in RH, implies that manure conditions were moister for the high efficiency group. As discussed in Chapter 2, methane is a by-product of anaerobic bacterial decomposition of organic compounds present in feed and excreta (Fabbri et al., 2007). Therefore, it is likely that methane would be produced at higher concentrations under the preferred condition occurring
in high efficiency excreta.

Table 11 Methane Results

<table>
<thead>
<tr>
<th></th>
<th>High</th>
<th>Low</th>
<th>Difference (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentration (ppm)</td>
<td>0.0713 ± 0.118</td>
<td>0.0668 ± 0.109</td>
<td>6.43</td>
</tr>
<tr>
<td>Emission (mg/h)</td>
<td>0.947 ± 3.08</td>
<td>0.864 ± 2.86</td>
<td>9.11</td>
</tr>
<tr>
<td>Emission Rate (kg/head/year)</td>
<td>0.00414 ± 0.0134</td>
<td>0.00378 ± 0.0125</td>
<td>9.11</td>
</tr>
<tr>
<td>Emission Factor (g/day/AU)</td>
<td>2.30 ± 3.73</td>
<td>3.46 ± 5.54</td>
<td>40.1</td>
</tr>
</tbody>
</table>
Figure 46 Methane Emissions with Genetic Line Comparison
Figure 47 and Figure 48 depict the average hourly methane emission rate for both the high and low efficiency groups, respectively. For the low efficiency group, there is an evident increase around 8:00 which continues until approximately 11:00. The time spent in the chamber is highlighted by the dotted line. At 8:30, the low efficiency turkeys are placed in the chamber, therefore the increase in the EF would be due to the introduction of the turkeys into the chamber. The methane then drops relatively consistently until 16:30. Unlike CO₂, the CH₄ emissions continue even after the turkeys are removed from the chamber, indicating that the litter substrate is the source of the CH₄ generation. This emission pattern is fairly consistent with the literature reviewed in Chapter 2, as the birds being introduced to the chamber are more active initially. Stress from transportation may also be a factor in the EF, as stresses such as heat stress can induce diarrhea (Brown-Brandl et al., 1997).

For the high efficiency group (Figure 47), there is a similar peak as the bird enters the chamber. However, it is fairly consistent with the level generated throughout the day with the birds present or not present. There are similarities between the two groups, as both experience a general upwards trend at 7:00 - 8:00 followed by low point around noon. In the low efficiency group, there is a slight uptick that occurs at 15:00. Both groups show a general downtrend after the birds have left the chamber. This slight downward trend continues until around 00:00 where both groups experience a slight rise in methane, the magnitude is more noticeable for the low efficiency group. The main argument for the sharp decrease would be that from the physical removal of the birds no more manure would be deposited, and no bird activity to initiate mixing which catalyses the production of methane gases. By removing the birds from the chamber, the pollutant creation is limited to the remaining excreta left in the chamber.
Figure 47 Average Hourly Methane Emissions High Efficiency Group

Figure 48 Hourly Methane Emissions Low Efficiency Group
6.7.2.4 Methane Cumulative Emission

In order to illustrate the difference in CH₄ emitted from the two genetic lines, the cumulative emission was calculated, as seen in Figure 49. The cumulative emissions (g) from the environmental chambers for both genetic lines were calculated for the entire campaign. Throughout the sampling cycle, the low efficiency cumulative emission exceeded the high efficiency group. Overall, the total difference of methane (g) emitted between the two groups was 41.6%.

![Figure 49 Cumulative Emission for Methane](image-url)
6.7.3 Ammonia Results

6.7.3.1 High and Low Efficiency Results

The stacked graphs for ammonia concentrations, body weight, and emission factor for the high efficiency group for the whole campaign are given in Figure 51. Similarly, Figure 52 depicts the stacked graphs for the low efficiency birds. During the campaign, there was a mechanical shutdown of the research building which produces the gaps in the data from 04/29/16 to 05/02/16.

The graphs displayed in Figure 51 highlight the concentration of ammonia in ppb, the body weights of the animals that were used for monitoring, and the emission factor calculated with the exhaust rate and weight of the animal. The system was set to analyze for 20 minute intervals. First, the high efficiency chamber was monitored, followed by the low efficiency chamber, and then the room for a baseline reading. Therefore, to get the adjusted concentration of ammonia from the turkey chamber, the baseline room concentration was subtracted from the bird chamber concentration. Figure 50 depicts the unmodified concentrations of NH$_3$ for the chambers and room.

Towards the end of the trial, there appears to be more leaking of ammonia into the room. This suggests a fault in the chambers, as they did not contain all of the contaminated air.

As seen in the stacked graphs, NH$_3$ emissions followed a diurnal pattern, a trend that was seen throughout the sampling campaign. In order to determine the independence of the low and high efficiency genetic line’s emissions, a z-test was performed and returned a $p$-value of $< 0.0001$. This value indicates that the two datasets are statistically independent. During the sampling campaign, the emissions increased and decreased by time of day. This pattern can be observed in Figure 54 and Figure 55 where ammonia EFs increase towards the end of the trial.

Unlike CO$_2$, ammonia emission factors do not appear to rely heavily on body weight.
On days where the body weights dip below the average, there is no evident reduction in emission factors, contrary to the results for CO$_2$. This suggests that ammonia generation depends on other factors. The likelihood of ammonia volatilization increases under wet conditions, in combination with higher temperatures, and increased pH values. Those conditions have been documented as advantageous for reactions that generate ammonia and increase volatilization (Follett, 1995).

Similar to the high efficiency group, the low efficiency ammonia emissions show a diurnal trend throughout the campaign. Ammonia concentrations and EFs for the low efficiency group appear to be independent of body weight. Both groups follow a similar trend, which is caused by having similar environmental conditions. In both Figure 35 and Figure 36, where temperature and relative humidity inside the chamber are shown, both high efficiency and low efficiency chambers have parallel conditions.
Figure 51 High Efficiency Group Ammonia Concentrations, Body Weight and Emission Factors
Figure 52 Low Efficiency Group Ammonia Concentrations, Body Weight and Emission Factors
6.7.3.2 Ammonia Comparison

Ammonia emissions generated by the high and low efficiency groups follow a similar diurnal trend and both groups increase and decrease in the same manner. Similar to methane and carbon dioxide, when observing the concentration (ppm) of ammonia, the difference between the two groups is not significant ($p = 0.706$). For both groups, it appears that emission was not affected by body weight as much as that observed for CO$_2$. Other factors such as temperature, moisture, and pH influence the generation and volatilization (Trudell, 2014). Based on temperature and relative humidity graphs, the conditions in the chambers were comparable.

The pH of the manure is comparable between the two groups. The high efficiency manure had an average pH of 6.64, compared to 6.86 for the low efficiency group. However, looking at Figure 53, the low efficiency group had a higher emission factor throughout the campaign. Therefore, the low efficiency group produced more ammonia on a per animal unit basis than the high efficiency group ($p < 0.0001$). The average concentration, emission rate, and emission factor for the low and high efficiencies are summarized in Table 12.

<table>
<thead>
<tr>
<th></th>
<th>High</th>
<th>Low</th>
<th>Difference (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentration (ppb)</td>
<td>16.4 ± 11.0</td>
<td>16.6 ± 10.2</td>
<td>0.832</td>
</tr>
<tr>
<td>Emission Rate (mg/h)</td>
<td>1.42 ± 0.951</td>
<td>1.56 ± 0.959</td>
<td>9.31</td>
</tr>
<tr>
<td>Emission Rate (kg/head/year)</td>
<td>6.23x10$^{-3}$ ±4.17x10$^{-3}$</td>
<td>6.84x10$^{-3}$ ±4.2x10$^{-3}$</td>
<td>9.31</td>
</tr>
<tr>
<td>Emission Factor (g/day/AU)</td>
<td>0.574 ± 0.362</td>
<td>0.971 ± 0.569</td>
<td>51.2</td>
</tr>
</tbody>
</table>
Figure 53 Ammonia Emissions with Genetic Lines Comparison
6.7.3.3 Ammonia Average Hourly Emission

The average hourly emission factor highlights certain trends in the generation of ammonia. Figure 54 shows the average hourly emission factors across the campaign for high efficiency and Figure 55 depicts low efficiency. The dashed line shows the time the birds were inside the chamber. For both efficiency groups, there is a sharp increase in the ammonia present in the chamber at 8:30. There should be a lag between the birds being placed inside the chamber and the ammonia spike, as there is minimal manure present. However, the lights are turned on in the penning room at 6:00 meaning the birds have been awake for two hours, eating and excreting. During this time, the birds will be active and moving around the penning room. The birds will have been mixing the manure with their feet, which leads to an increase in ammonia production. Manure will be transported into the environmental chamber via the birds’ feet. This phenomenon may also explain the dip in ammonia levels when the birds are taken out of the chamber at 16:30. However, the likely scenario is the ammonia contained in the chamber is released to the ambient air when the chamber is opened to remove the birds.

For both groups, the ammonia factors reach a peak at midnight, then experience a general downtrend until the birds are placed back inside the chamber. The increase of ammonia after 16:30 could be attributed to the reactions in the manure creating the gas. It appears as though the reaction appears to be completed at midnight, resulting in a reduction of ammonia emissions. During the campaign, it was observed that the low efficiency group was less active during the day than the high efficiency birds. Bird activity would act as a mixer between the deposited excreta and litter substrate. Thus, less bird movement may have resulted in lower emissions.
Figure 54 Average Hourly Ammonia Emission Factor for High Efficiency

Figure 55 Average Hourly Ammonia Emission Factor for Low Efficiency
In order to illustrate the difference in NH$_3$ emitted from the two genetic lines, the cumulative emissions for each line was computed, as seen in Figure 56. The cumulative emissions (g) from the environmental chambers for both genetic lines were calculated for the entire campaign. Throughout the sampling cycle, the low efficiency cumulative emission was larger than the high efficiency group. Overall, the total mass difference of ammonia emitted (g) between the two groups was 50.8%.
6.8 Emission Factors

A summary of emissions (average, high, and low) are presented in Table 12 for the two genetic lines. Compared to literature values, methane is similar in terms of kg/yr/head, while ammonia is considerably lower than previously documented values. The main explanation for this would be the experimental setup, primarily the number of birds studied and the manure clean out frequency. Most studies involve research on a barn housing hundreds of birds. These barns undergo standard practices for manure cleanout. Manure cleanout typically occurs after several flocks have been raised. For this experiment, to avoid uncertainty over the direct factor of emissions, the manure was cleaned out daily. The reasoning was to determine emission factors at a bird level, rather than having the manure build up as a group. Therefore, the manure only had 24 hours to mix and react to create gaseous emissions. Based on this, it is reasonable that ammonia emissions were considerably lower than at the farm scale.

The ammonia, methane, and carbon dioxide emission factors were higher for the low efficiency group. This is encouraging, as it would suggest that the high efficiency genetic line emits less of these pollutants per AU. Ammonia and methane production is heavily dependent on manure production. This would indicate that the high efficiency group would produce less excreta per amount of food that is eaten with less wasted nitrogen. Therefore, by genetically modifying these birds to improve feed efficiency lower emissions of ammonia, methane, and carbon dioxide can be achieved. This is great first step to understanding how FCR can relate to direct and indirect GHG emissions.
Table 13 Summary of Emissions

<table>
<thead>
<tr>
<th>Genetic Line</th>
<th>CO2</th>
<th>CH4</th>
<th>NH3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Average</td>
<td>$4.67 \times 10^4 \pm 1.59 \times 10^4$</td>
<td>$6.54 \times 10^4 \pm 2.19 \times 10^4$</td>
<td>$2.30 \pm 3.73$</td>
</tr>
<tr>
<td>Minimum</td>
<td>46.9</td>
<td>0.443</td>
<td>0.0019</td>
</tr>
<tr>
<td>Maximum</td>
<td>$1.65 \times 10^5$</td>
<td>$1.67 \times 10^5$</td>
<td>29.074</td>
</tr>
</tbody>
</table>

Note: All figures are given in units of (g/day/AU)
6.9 Nitrogen Balance

A nitrogen balance was developed for both groups, to further understand the potential for ammonia to be generated. As previously discussed, the lower efficiency group required more feed than the high efficiency group to increase mass. This indicates that if both groups are given the same amount of feed, more of these nutrients will be used by the high efficiency birds for mass gain compared to the low efficiency. The nutrients that are not used are deposited into the environment as excreta. Therefore, the low efficiency group will excrete nitrogen at a higher rate than the high efficiency group. This extra output of nitrogen leads to the generation of ammonium and the eventual volatilization of ammonia.

The nitrogen balances are estimated from feed intake, amount of manure generated, and ammonia emission rates (refer to Figure 57 and Figure 58). The nitrogen balance is assessed off 1000 g of feed intake and 11 kg of turkey. 1000 g was selected as a base unit, and 11 kg was selected as it was the only average bird weight in the chamber that was applicable to both groups. The total nitrogen found in the turkey feed is 3.18%, therefore per 1000 g of feed, the nitrogen intake is 31.8 g. The high efficiency group reached the bird weight of 11 kg on the first day (04/16/16) of the experiment; the low efficiency group reached 11 kg on the last day (05/15/16).

To derive the nitrogen in the feed intake, the average daily feed ingested per bird was multiplied by the percentage of nitrogen in the feed. The total kjeldahl nitrogen of the feed was tested at University of Guelph Lab services. During the last week of testing, the weight of the bedding was measured before the birds went into the chamber and after. The difference in weight is attributed to the weight of manure excreted during the day. The manure was tested for nutrients as well (listed in Table 8 and Table 9 for low efficiency and high efficiency, respectively). To determine the amount excreted, the average nitrogen percentage was multiplied by the weight of the manure. The average TKN % was 1.328 for low efficiency and 1.123 for high efficiency. The losses were estimated to be the amount attributed to ammonia. Nitrogen from ammonia was
calculated based off the average mg/h for the whole campaign then transformed to a weight based off 24 hours. All other nitrogen calculations in the balances were based off daily averages (e.g. the sum of food for the whole campaign divided by campaign length).

As depicted in Figure 57 and Figure 58, the low efficiency group only produced 0.0318 more gN of ammonia than the high efficiency group. However, this does not take into account the total amount of feed input into each system. For the low efficiency group, 0.41% of the nitrogen in the feed was converted directly to ammonia, compared to 0.29% for the high efficiency group. This figure seems small; however, it should be considered that by only examining two birds at a time and cleaning out manure daily, the NH₃ generated is limited. If examined in a barn housing 1000 turkeys, this difference can attribute to higher emissions per mass of feed. Also, the mean EF for low efficiency was almost 100% higher than the high efficiency at 0.971 and 0.574 g/day/AU, respectively.

The nitrogen balances are based on the mg/h emission rates, which does not take into account the bird weights. The high efficiency birds are on average 6 kg heavier and eat 57.9 g more feed per day (equates to 1.81 gN). Therefore, low efficiency birds on average generate more ammonia while being smaller and eating less than the high efficiency birds. The high efficiency birds generated 3.65 mg NH₃/g(feed) compared to 5.00 mg NH₃/g(feed). When body weight is taken into account, the difference becomes more significant. The high efficiency group would produce 49.19 mg NH₃/AU per gram of feed compared to 106.64 mg NH₃/AU per gram of feed for the low efficiency group.
Figure 57 High Efficiency Nitrogen Balance

Figure 58 Low Efficiency Nitrogen Balance
7.0 Conclusion

The objective of this study was to determine if a relationship is present between the greenhouse gas emissions, namely CH$_4$, NH$_3$, and CO$_2$, and feed efficiency. To determine if there is a relationship, data was collected from two different genetic lines of turkeys. The turkey production trait used as a cornerstone for comparison was feed efficiency, a trait that can be identified through feed conversion efficiency. Through the use of a predetermined sampling protocol and proper equipment, the pollutant emissions were recorded over the course of a 28-day sampling period. This study had a unique objective and should be considered a first step in developing the relationship between FCR and EFs and how it can translate to the industry.

The feed conversion ratio was the production trait assessed in this study. The ability to process feed and convert the nutrients to animal mass has a direct impact on production quality; while it has been hypothesized that it could also be beneficial to reduce greenhouse gases. Feed conversion ratios were calculated to be 2.004 and 3.135 for high and low efficiency, respectively ($p = 0.027$). This difference in feed conversion leads to the low efficiency group producing a higher concentration of nitrogen in the excreta. The FCR results fall in line with values found in literature.

As discussed, ammonia and methane emissions in poultry are directly linked to the excreta deposits. These are affected by environmental factors such as temperature, pH, and moisture content. However, in this study the emissions were monitored under parallel conditions. This suggests that any difference in emissions would not be due to environmental conditions, but to production traits which alter the excreta.

It was found that the concentration (ppm) of the all three pollutants were not significantly different between the two genetic lines for CO$_2$ ($p = 0.343$), CH$_4$ ($p = 0.291$), and NH$_3$ ($p = 0.706$). Although the concentrations from two birds of different groups are similar, when emission factors are calculated, the low efficiency group is emitting far higher levels of pollutants per animal unit.
Overall, the low efficiency turkeys were found to have 33.2% ($p < 0.0001$), 40.1% ($p = 0.00113$), and 42.5% ($p < 0.0001$) higher emission factors for carbon dioxide, methane, and ammonia. The increase in the difference when calculating an EF based on AUs is due to the inclusion of the body weight. This calculation allows the model to include the weight gained and determine the emission on an animal unit basis, rather than just a raw concentration. Due to this, the difference in emissions between high and low efficiencies become more clear.

For carbon dioxide emissions and methane emissions, it was observed that for both pollutants, the concentrations were higher for the high efficiency line but after EF was calculated, low efficiencies produced more. Although CO$_2$ can be related to fecal deposition of carbon in untouched manure, the majority of the generation at bird level comes from respiration. Therefore, production traits such as feed conversion do not necessarily effect or limit the amount of CO$_2$ produced.

As for the emission factors, NH$_3$ and CO$_2$ demonstrated a significant drop between the two genetic lines ($p=<0.0001$). For CH$_4$, the difference in emission factors between the two groups was found to be 40.1% ($p = 0.00113$). However, due to the high number of zero values in the data and the standard deviation larger than the mean, methane EFs were determined to be not statically significant.

By evaluating the emissions on an animal unit basis, we can assume the trend for larger productions. By sampling on a per bird basis, the emission factor can be applied to 500 kg of live mass, from which a better assessment can occur. Comparing genetic lines, the low efficiency line would emit 51.2%, 40.1%, and 33.2% more ammonia, methane, and carbon dioxide respectively. Therefore, by genetically modifying these birds to improve feed efficiency, it can also lead to fewer emissions of ammonia, methane, and carbon dioxide. This is great first step in understanding how FCRs can relate to direct and indirect GHG emissions.
8.0 Recommendations

The objectives of this study were completed, however if this study or a similar study were to be repeated, there are some improvements that could be applied. The following points outline the recommendations that should be followed to enhance future studies.

- The study was conducted in an environmental chamber to determine a difference at bird level. The objectives were met; however, ammonia levels were considerably lower than literature values. This was due to several factors including, frequency of waste cleanout, incorporation of only two birds at a time, and having the birds in the chamber for 8 hours, not a full day. Therefore, it would be advantageous to develop the study further by examining emission factors produced by turkeys throughout a 24-hour period. This would lead to more mixing and generation of pollutants.
- Additionally, as this was a pilot trial to determine if any variance can be detected, further studies should be conducted in a barn to develop real world models. By obtaining data from barns housing significantly more turkeys, emission factor differences between the two lines of birds can be developed further. This is due to same reasons listed above, as more turkeys, with the addition of 24-hour monitoring period, and less frequent manure cleanup could lead to more involved results.
- Manure samples were collected throughout the campaign; however, no manure was collected from the chambers. If tested, it could have led to greater insight for the drop in emission after 12:00. It is theorized that the manure would have dried up overnight and thus limited the reaction that generates ammonia and methane. If the manure had been tested, this theory could have been validated.
- Mass of the manure is required to develop a nitrogen balance. The data for this procedure was only collected in the last week of the trial. It would have been beneficial to weigh the samples throughout the campaign. In order to
include this data into this study and enhance the nitrogen balances, samples should be taken on a more frequent basis and analyzed under the same conditions as other nitrogen factors such as feed and manure characterization.

- The exhaust fans were tested a limited amount during the campaign. The system was uninhibited by environmental conditions, and thus believed to be operating at the same flow rate throughout.

- Based on the results that show that the high efficiency turkeys produce lower ammonia, methane, and carbon dioxide on an animal unit basis, a life cycle analysis on the greenhouse gas emissions should be performed. To get a full evaluation, a review of the upstream feed production should be conducted, as well as the downstream litter use. This evaluation would provide a total picture of the reduction in greenhouse gases from using turkeys with higher feed conversion ratios.
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doi:10.3382/ps.0731785

Comparison of the performance of 1966- versus 2003-Type turkeys when fed


Michael, M., Menashe, D. N., & Tel, I. Retrieved September 29, 2016, from http://www.plassonlivestock.com/content/page/Drinker-for-Turkeys


## Appendix A Lab Results

### A1 Manure Results

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<th>Test</th>
<th>Result</th>
<th>Units</th>
<th>Note</th>
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*University of Guelph - 35 Stone Rd West, Guelph, ON N1H 6J7 - www.guelphlabservices.com*
### Manure Package

**Date Authorized:** 2016-May-10 15:20

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### pH

**Method ID: SNL-021**

**Date Authorized:** 2016-May-10 15:20

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<th>Note</th>
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Supervisor: Nicolas Schrier MSc, Animal Health Laboratory 510 823 1268 ext. 57215 neschrier@uoguelph.ca

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<table>
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<th>Sample ID</th>
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<th>Sampling date / time</th>
<th>Test</th>
<th>Result</th>
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**pH**

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**Supervisor:** Nicolaas Schrier MSc, Animal Health Laboratory 519.823 1268 ext. 57215 nschrier@uoguelph.ca
UNIVERSITY OF GUELPH
CLAYTON GIONET
SCHOOL OF ENGINEERING
50 STONE RD E
GUELPH, ON N1G2W1

Phone: 519 824-4120
Sampling Date: 2016-May-12
Received Date: 2016-May-12

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<td>LOW EFF</td>
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**Manure Package**  Method ID: CHEM-039, 185, SNL-019, TOXI-024

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<th>Test</th>
<th>Result</th>
<th>Units</th>
<th>Note</th>
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**pH**  Method ID: SNL-021

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<th>Units</th>
<th>Note</th>
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## A2 Feed Results

**UNIVERSITY OF GUELPH**
LABORATORY SERVICES
Agriculture and Food Laboratory

Submitted By:  
Client ID:  1773990  
UNIVERSITY OF GUELPH  
CLAYTON GIONET  
U OF G SCHOOL OF ENGINEERING  
GUELPH, ON N1G 2W1

Phone: 519 824-4120  
Fax: 519 836-0227  
Sampling Date: 2016-May-06  
Received Date: 2016-May-06

### Total Nitrogen  Method ID: SNL-006

Date Authorized:  2016-May-10  15:14

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<th>Result</th>
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</table>

Supervisor: Nicolaas Schrier MSc, Animal Health Laboratory 519 823 1268 ext. 57215 nschrier@uoguelph.ca

---

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Agriculture and Food Laboratory - 95 Stone Rd West, Guelph, ON N1H 8J7 - www.guelphlabservices.com  
Printed:  2016-May-10
Appendix B Bird Weights

B1 All Birds

Table B-1 Low Efficiency Bird Weights

<table>
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<th>Bird ID</th>
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* Interpolated Weights
## Appendix C Feed Intake

C1 Chamber Feed

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C2 Penning Room Feed

Table C-3 Pen Room Feed Intake

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Appendix D Animal Utilization Protocol (AUP)

D1 Training Sheet

Training Sheet

AUP 3137 Dr. B. Wood Genetic relationship feed efficiency and GHG emissions in turkeys

Dr. Benjamin Wood

<table>
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<tr>
<th>Courses</th>
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<th>Training and Species</th>
<th>Core Modules Cohort</th>
<th>Location</th>
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Clayton Gionet

<table>
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<td>Poultry - hands on workshop</td>
<td></td>
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A new tab, titled Approved, was added. This tab will appear for all AUPs, but will only be populated once an AUP is approved for the first time. View the Approved version for currently approved information. For editing, updating or viewing information currently under review, please continue to use the View and Edit tabs as usual.

Section 1: Background

Status: Not submitted
1.1 Principal Investigator or Instructor: Benjamin Wood, Animal And Poultry Science
1.3 Project Name: Genetic relationship feed efficiency and GHG emissions in turkeys
1.4 Project Category: Research
1.6 Purpose of Animal Use: Studies of a fundamental nature in sciences relating to essential structure or function (e.g. biology, psychology, biochemistry, pharmacology, physiology, behaviour, etc.)
1.7 Classification: Chronic - Maintaining the animal and performing experimental procedures during this time, i.e. feeding trials, antibody production, breeding colony, recovery surgery.
1.8 For RESEARCH projects is this a pilot study?: Yes
1.9 If this application replaces an existing AUP, please enter the previous AUP number.: No

Section 2: Lay Summary / Public Relations

2.1 Research problem(s) or instructional principle(s) this project addresses (Background and Objectives): This project aims to create an enclosed gaseous exchange system wherein the production of GHG can be measured for a small group of turkeys. Turkeys will be grouped by high feed efficiency and low feed efficiency, and then compared for GHG gas emissions. Using previously determined feed efficiency, production traits and pedigree information a genetic basis for GHG emissions can then be determined. Once GHG production is quantified and compared to other consistently measured production traits, the turkey industry will be able to assess its environmental impact on a per bird basis, and have the option of including this in future selection decisions.
2.2 Anticipated impact (specific), potential benefits to human and/or animal welfare (Relevance of Research or Instruction): While nutritional strategies have achieved some success in reducing the environmental impact of livestock and poultry production, greenhouse gas (GHG) emissions continue to be a challenge. Lowering emissions will make the industry not only more environmentally friendly, but also more profitable.

Section 3: Funding and Peer Review

3.1 Has funding been approved for this study?: Yes
3.2 Sponsor: Canadian Poultry Research Council (CPRC)
3.3 Program name: Poultry Cluster

Funding Sources

3.5.1 Title of Grant: CPRC Poultry Cluster Grant
3.5.2 Grant Timeline: Tuesday, April 1, 2014 to Saturday, April 1, 2017
3.6 Peer Review for Scientific Merit of Research Studies or Educational Merit of Teaching protocols has been/will be performed by: Granting Agency
3.5.4 Additional Sponsors or Funding Sources:

https://www.uoguelph.ca/research/services-divisions/acc/animal-utilization-protocol/print... 29/07/2015
Title of Grant:
PIC GHG Emissions Grant Project 311

Grant Timeline:
Tuesday, April 1, 2014 to Saturday, April 1, 2017

Title of Grant:
Hybrid GHG Emissions Grant 2014

Grant Timeline:
Tuesday, April 1, 2014 to Saturday, April 1, 2017

Please attach relevant portions of the additional grant(s) or applications(s) that provide background information on the research problem, as well as detailed animal care and procedural information.

Section 4: Hazards

4.1 Does your project involve any hazardous materials or situations?:
No

Section 5: Personnel

1.2 Assignee:
Clayton Gionet

5.1 Chair of Department:
E. James Squires, Animal and Poultry Science

5.2 Designated Emergency Contact(s):
Benjamin Wood, Animal And Poultry Science
Clayton Gionet

5.3 Associate(s) and Facility Contact (s):
Heather D Bailey, Animal &amp; Poultry Science
Animal and Poultry Science (ANNU), Animal &amp; Poultry Science

5.5 Designated Veterinarian(s):
Marcus Litman, OR

5.6 Graduate and Undergraduate Students, and Teaching or Research Assistants:
Clayton Gionet

Section 6: Animals

Animal Details

6.1.1a) Quantity: 20 6.1.1b) Species: turkeys 6.1.1c) Strain: Large White 6.1.1d) Age: 19

6.1.1e) Age Unit: Weeks 6.1.1f) Gender: Male and Female

6.1.4 Sources:
6.1.4a) Indicate the source or supplier: Donor or Owner of Private Facility Name:
Client-Owned
Ben Wood

Company or Private Farm/Facility Name: Name of Facility of Colony/Herd/Flock:
Hybrid Turkeys
Hendrix Genetics

Street: 650 Riverbend Drive, Suite C City: Kitchener Province / State: ON Country: Canada Postal Code: N2K 3S2 Phone Number: 1 519 578 2740

Disposition

6.1.5 Disposition:
6.1.5a) Type:
Euthanasia

6.1.5b) Quantity:

https://www.uoguelph.ca/research/services-divisions/acc/animal-utilization-protocol/print... 29/07/2015
6.1.3 Who is performing routine daily observations of the animals?:
Facility Staff and Research Team Members
6.1.3a If research team members or owner are responsible for daily checks, please describe how it will be recorded this is done.: Daily checks will be performed by both Animal and Poultry Science staff, as well as the grad student. The events will be marked down on a timesheet, with a section for notes.

6.1.2 Accommodation Locations:
6.1.2a Animal Housing Facility:
Animal and Poultry Science (ANNU Building)
6.1.2b Animal Housing Facility Room Number:
ANNU 056
6.1.2c Experimental Facility/Area:
Animal and Poultry Science (ANNU Building)
6.1.2d Experimental Facility/Area Room:
ANNU 056

6.2 Explain how the total number of animals to be used was determined.: The number 20 was selected as the lowest possible limit to attain meaningful results while also reducing the number of animals required. This study is a pilot trial to understand if there is variance present. This is also a study that has yet to be measured in turkeys therefore we need a large enough population size in order to run different trials. This experiment structure is similar to "Validation of a short-term methane measurement using portable static chambers to estimate daily methane production in sheep" an experiment prepared by EP Groopy et al. In this they conducted an experiment to determine if the use of a chamber would give accurate results, in which they used 13 sheep. The idea of the isolation chamber was then used by a group at ANNU in which their experiment and ours share similar methodologies. They used chambers to determine if methane emission and CO2 production is heritable and repeatable even after adjustment for liveweight. Their procedure used 24 sheep on a rotating schedule. Based off those two experiments and the uniqueness of ours it was determined that in order to be able to identify a measurable difference in a pilot study, 20 birds would be required.

6.5 Describe the characteristics of the species or strain that make it appropriate for the research or teaching objectives.: The animals involved in the experimental procedure will be of two separate groups; a high group, with previously calculated excellent feed efficiency, and a low group, with poorer feed efficiency. The purpose of this experiment is to determine if there is a statistical difference in the amount of greenhouse gasses produced by turkeys of high feed efficiency and turkeys with low.

6.6 Explain the necessity of using animals:
Since we are determining gaseous concentrations produced from turkey's it is ultimately necessary that live birds are used in the experiment. There is no other alternative available that will provide the same level of data.

6.8 Specify the environmental enrichment provisions:
The housing pen will be of adequate size, bigger than the minimum requirement of .25 m2 of space per bird. The floor will be made of standard industrial practices. The water supply and feeders will be delivered by Animal and Poultry Science who will look after the birds daily. Adequate lighting, heating and ventilation have been heavily scrutinized and are adequate for the amount of birds in the experiment.

Section 7: Experimental and/or Animal Use Endpoint

7.1 Expected clinical conditions or abnormalities:
There should be no change in the conditions of the birds and no expected abnormalities. The experimentation will change nothing in terms of daily animal care as it is strictly only for observation of gasses generated by the animals.

7.2 Removal Criteria:
If any behavioral changes are noticed it will be brought straight to the attention of the convening veterinarian, as well as Dr. Ben Wood were they can make an informed decision for the outcome.

7.3 When a health issue or injury unrelated to the experiment occurs, is regular veterinary care appropriate for the animals?:
Yes

7.3.1 Please provide your explanation here:
No, we are strictly observing gaseous concentrations emitted from the turkeys under normal industrial conditions, therefore there is no variable that would disrupt experimentation such as use of anti-inflammatory.

https://www.uoguelph.ca/research/services-divisions/acc/animal-utilization-protocol/print... 29/07/2015
Section 8: Procedures

8.1 Procedures:
8.1.1a Species: turkeys
8.1.1b Strain: Large White
8.1.1c Quantity: 10
8.1.3 Drugs administered to this animal:

8.1.2 Procedures performed on this animal:
8.1.2a Name of Procedure:
Other
8.1.2b If you specified other, please provide further details:
Monitoring concentrations of greenhouse gasses emitted by the turkeys
8.1.2c Extra information:
Each group of turkeys will have its gas exchange monitored continuously.
8.1.2e Procedure to be performed by:
Name:
Clayton Giomet.

8.4 Give a sequential description of the use of animals in this teaching exercise or research project.:
The turkeys will be held in air-tight ventilated plexiglass cages constructed to house a small group (5) of turkeys over a period of 1.5 weeks. They will be feed and supplied water by the technicians from Animal and Poultry Science. The animals involved in the experimental procedure will be of two separate groups; a high group, with previously calculated excellent feed efficiency, and a low group, with poorer feed efficiency. Outside air will be circulated into the plexiglass cages and after removal of water vapor, a sub-sample of the expired air will go to inline analyzers for NH3, N2O, CO2, and CH4. Each group of turkeys will have its gas exchange monitored continuously throughout the day. In addition, the gaseous composition of the room will be monitored for later calculation of the gas consumption (O2) and production of NH3, N2O, CO2, and CH4 by the turkeys.

8.5 Specify the frequency of observations and methods for monitoring the condition of the animals.:
Animal and Poultry Science staff will take care of the birds daily, as well the graduate student will make daily trips to monitor the analyzers as well as the conditions present in the chamber.

8.7 List individuals who will be monitoring the animals:
Clayton Giomet.

8.8 List groups who will be responsible for monitoring the animals:
Animal and Poultry Science

8.9 Explain refinements implemented to minimize pain, distress and/or discomfort to the animals, e.g. modified procedures:
The turkeys will be held in groups as to reduce distress of isolation. The gaseous levels of the greenhouse gasses will also be checked daily to remain within the daily allowable limits determined by the Ontario Government.

Review

ANIMAL CARE COMMITTEE APPROVAL

FOLLOWING APPROVAL, A PROTOCOL NUMBER WILL BE ASSIGNED. THIS NUMBER MUST BE USED WHEN ORDERING ANIMALS AND IT IS UNDERSTOOD THAT THESE ANIMALS WILL BE USED ONLY AS DESCRIBED IN THIS PROTOCOL.

THIS ANIMAL UTILIZATION PROTOCOL IS VALID FOR A PERIOD OF UP TO 12 MONTHS FROM THE DATE OF COMMENCEMENT.
THE ANIMAL CARE COMMITTEE WILL REQUEST ANNUAL REVIEWS FOR ALL PROTOCOLS.
THE ANIMAL CARE COMMITTEE CAN PROVIDE EXTENSIONS BEYOND THE 12 MONTH PERIOD, FOR A MAXIMUM OF 4 YEARS IN TOTAL.

https://www.uoguelph.ca/research/services-divisions/acc/animal-utilization-protocol/print... 29/07/2015
MATERIAL TRANSFER AGREEMENTS (MTAs)

MTAs may be required to protect the rights of the parties involved in the exchange of biological materials for research purposes. For advice and assistance in this regard, please contact the Administrative Assistant, Business Development Office, 519-824-4120 ext 58878.

DECLARATION

THIS ANIMAL UTILIZATION PROTOCOL ACCURATELY DESCRIBES ALL THE PROPOSED ANIMAL USE. IT WILL BE KEPT CURRENT AND WILL BE MODIFIED ONLY AFTER OBTAINING THE APPROVAL OF THE ANIMAL CARE COMMITTEE.

ALL PROCEDURES WILL BE CARRIED OUT BY PERSONNEL LISTED IN Q89 WHO ARE TRAINED AND COMPETENT IN USING APPROVED TECHNIQUES.

AN ANIMAL INCIDENT REPORT WILL BE FAXED TO THE DIRECTOR, ANIMAL CARE SERVICES, WITHIN 24 HOURS OF ANY UNEXPECTED PROBLEMS OR COMPLICATIONS INVOLVING ANIMAL HEALTH AND WELLBEING IN THIS STUDY. (AN ANIMAL INCIDENT REPORT IS AVAILABLE (HTTP://WWW.UOGUELPH.CA/RESEARCH/FORMS_POLICIES_PROCEDURES/ANIMAL_SHTML) FOR THIS PURPOSE.)

ALL ANIMALS USED IN THIS RESEARCH/TEACHING PROJECT OR DISPLAY WILL BE CARED FOR IN ACCORDANCE WITH

- THE RECOMMENDATIONS OF THE CANADIAN COUNCIL ON ANIMAL CARE,
- THE REQUIREMENTS OF THE ANIMALS FOR RESEARCH ACT REvised STATUTES OF ONTARIO, 1990, CHAPTER A.22,
- THE UNIVERSITY OF GUELPH ANIMAL CARE POLICY.

Chair Signature: E. James Squires
Chair Sign Date: Wednesday, December 24, 2014
Approval Dates:

https://www.uoguelph.ca/research/services-divisions/acc/animal-utilization-protocol/print... 29/07/2015
Animal Incident Report

Facility: ANNU Animal Wing
AUP #: 3137

Reported by: Clayton Gionet
Position: Research Assistant

Time of Incident: 8:30 am
D/M/Y of Incident: 04-05-2016

D/M/Y Reported: 04-05-2016

DESCRIPTION OF INCIDENT: State exactly what was leading up to the incident, where the incident occurred etc:
Two toms broke their wings during handling in the pen prior to being moved to the environmental chamber in ANNU 050.
The incident occurred in ANNU 050.

ANIMALS AFFECTED:

Total #2
Gender: Male
Species: Turkey

MORBIDITY / MORTALITY #’s - Describe how the animals were affected:
Tom 303 suffered a broken wing that will heal if left alone. He remains in the pen in ANNU 050 for the duration of the trial (another 11 days) and will not be used for testing in the environmental chamber.
Tom 308 suffered a broken wing and was euthanized by Caitlin Woolcott, Dept of Animal Biosciences since Ben Wood was not available.

CAUSE OF SICKNESS OR DEATH (IF KNOWN):
Broken wing suffered from flapping its wings while being handled.

ACTION PLAN:
Tests to be performed:

By Whom:
Contributing Factors: What conditions contributed to the incident:
The research protocol requires that 2 random toms from each group (low and high efficiency) be placed in the environmental chamber daily and

Clayton has been handling them to read their tag #s before selection.

Control Measures:

Recommendations for Corrective Measures:
1. Clayton to spend more time (15 mins) in pen before handling the birds. Toms are becoming more interested in new entrants to pen. Added time in pen will aid in acclimatizing to the handler and should decrease reaction to handling.
2. Birds do not need to be picked up to check IQ band - this can be achieved with bird on the ground by using small spots of yellow and orange paint placed on tail (these colours are already used in each population) - this will ensure
bird do not need to be handled for candidate selection.

3. Transport cart to use a larger box so that bird cannot grab edge when transferred between environmental chamber and housing rooms.

4. Firm handling of bird close to body to stop bird straining or flapping. Alternative technique holding wing and leg can be used if required.

Signature of Person Reporting Incident:  Clayton Gionet/Ben Wood   Date:  May 5/16
D3 Approved AUP

1/10/2017

Welcome! Please take a moment to fill out your user profile.

151

AUP #

1.1 Principal Investigator or Instructor:
   Benjamin Wood, Animal And Poultry Science

1.3 Project Name:
   Genetic relationship of feed efficiency and greenhouse gas emissions in turkeys

8.2 What is the highest distress or pain level associated with any of your procedures?: C

Section 1: Background

Section 2: Lay Summary / Public Relations

2.1 Research problem(s) or instructional principle(s) this project addresses (Background and Objectives):

This project aims to create an enclosed gaseous exchange system wherein the production of greenhouse gas (GHG) can be measured for a small group of turkeys. Turkeys will be grouped by high feed efficiency and low feed efficiency, and then compared for GHG gas emissions. Using previously determined feed efficiency, production traits and pedigree information, a genetic basis for GHG emissions can then be determined. Once GHG production is quantified and compared to other consistently measured production traits, the turkey industry will be able to assess its environmental impact on a per bird basis, and have the option of including this in future selection decisions.
2.2 Anticipated impact (specific), potential benefits to human and/or animal welfare (Relevance of Research or Instruction):

While nutritional strategies have achieved some success in reducing the environmental impact of livestock and poultry production, greenhouse gas (GHG) emissions continue to be a challenge. Lowering emissions will make the industry not only more environmentally friendly, but also more profitable.

Section 3: Funding and Peer Review

3.1 Has funding been approved for this study?: Yes

3.2 Sponsor:
Canadian Poultry Research Council (CPRC)

3.3 Program name:
Poultry Cluster

Funding Sources

3.5.1 Title of Grant:
CPRC Poultry Cluster Grant

3.5.2 Grant Timeline:
Tuesday, April 1, 2014 to Saturday, April 1, 2017

3.6 Peer Review for Scientific Merit of Research Studies or Educational Merit of Teaching protocols has been/will be performed by:
Granting Agency

3.5.4 Additional Sponsors or Funding Sources:
Title of Grant: PIC GHG Emission Grant Project 311
Grant Timeline: Tuesday, April 1, 2014 to Saturday, April 1, 2017
Title of Grant: Hybrid GHG Emissions Grant 2014
Grant Timeline: Tuesday, April 1, 2014 to Saturday, April 1, 2017

Please attach relevant portions of the additional grant(s) or application(s) that provide background information on the research problem, as well as detailed animal care and procedural information.

Section 4: Hazards

4.1 Does your project involve any hazardous materials or situations?: No

Section 5: Personnel

1.2 Assignee:
Clayton Gionet.

5.1 Chair of Department:
E. James Squires, Animal and Poultry Science

5.2 Designated Emergency Contact(s):
Benjamin Wood, Animal and Poultry Science
Clayton Gionet.

5.3 Associate(s) and Facility Contact (s):
Heather D Bailey, Animal Biosciences
Animal and Poultry Science (ANNU), Animal & Poultry Science
5.5 Designated Veterinarian(s):
Anna Bolinder, Animal Care Services
5.6 Graduate and Undergraduate Students, and Teaching or Research Assistants:
Clayton Gionet.
Section 6: Animals

Animal Details
6.1.1a) Quantity: 20
6.1.1b) Species: turkeys
6.1.1c) Strain: Large White
6.1.1d) Age: 19
6.1.1e) Age Unit: Weeks
6.1.1f) Sex: Male and Female
6.1.4 Sources:

6.1.4a) Indicate the source or supplier:
Client Owned
Company or Private Farm/Facility Name:
Hybrid Turkeys
Name of Facility of Colony/Herd/Flock:
Hendrix Genetics
City:
Kitchener
Province / State:
ON
Country:
Canada
Phone Number:
1 519 578 2740

Disposition
6.1.5 Disposition:

6.1.5a) Type:
Euthanasia
6.1.5b) Quantity:
20

6.1.3 Who is performing routine daily observations of the animals?:
Facility Staff and Research Team Members
6.1.3a) If research team members or owner are responsible for daily checks, please describe how it will be recorded this is done.:
Daily checks will be performed every hour for the trial time by both Animal Biociences staff, as well as the grad student. The events will be marked down on a timesheet, with a section for notes.

6.1.2 Accomodation Locations:

6.1.2a) Animal Housing Facility:
Animal and Poultry Science (ANNU Building)
6.1.2b) Animal Housing Facility Room Number:
ANNU 056
6.1.2c) Experimental Facility/Area:
6.2 Explain how the total number of animals to be used was determined:

The number 20 was selected as the lowest possible limit to attain meaningful results while also reducing the number of animals required. This study is a pilot trial to understand if there is variance present. This is also a study that has yet to be measured in turkeys therefore we need a large enough population size in order to run different iterations of the same trial. This experiment structure is similar to "Validation of a short-term methane measurement using portable static chambers to estimate daily methane production in sheep" (J.P. Goopy, R. Woodgate, A. Donaldson, D.L. Robinson, R.S. Hegarty, 2011). In this they conducted an experiment to determine if the use of a chamber would yield accurate results, in which they used 13 sheep. The idea of the isolation chamber was then used by the group The Animal Selection, Genetics and Genomics Network (ASGGN, http://www.asggn.org/) in which their experiment and ours share similar methodologies. They used chambers to determine if methane emission and CO2 production is heritable and repeatable even after adjustment for liveweight. Their procedure used 24 sheep on a rotating schedule. Based off those two experiments and the uniqueness of ours it was determined that in order to be able to identify a measurable difference in a pilot study, 20 birds would be required.

6.4 Indicate consideration given to reduce the use of animals:

Based off literature review of similar experiments it was determined that in order to be able to identify a measurable difference in a pilot study, 20 birds would be required. Consideration for reduction in animal size was done early in the design of protocol. We considered 20 to be the lowest amount of turkeys needed to fulfill the nature of the experiment while running our trials.

6.5 Describe the characteristics of the species or strain that make it appropriate for the research or teaching objectives:

The animals involved in the experimental procedure will be of two separate groups; a high group, with previously calculated excellent feed efficiency, and a low group, with poorer feed efficiency. The purpose of this experiment is to determine if there is a statistical difference in the amount of greenhouse gasses produced by turkeys of high feed efficiency and turkeys with low. By using these animals that are pre-selected for feed efficiency we are able to investigate a difference in methane production with more power and hence fewer animals than we would need if a random sample of birds were used.

6.6 Explain the necessity of using animals:

Since we are determining gaseous concentrations produced from turkey's it is ultimately necessary that live birds are used in the experiment. There is no other alternative available that will provide the same level of data. In this experiment we need to use turkeys and not a model species like mice. As the commercial application will be in turkeys, the point of the experiment is to measure differences in turkeys. The method itself has been used in other species such as sheep as described.

6.7 Indicate any alternatives to animal use already incorporated into the project design or course design (in vitro/cells in vivo):

Since we are monitoring the emissions from the animals, it is required that an animal be present for the testing. Therefore there are no alternatives to animal use for this project.
6.8 Specify the environmental enrichment provisions:

There will be two chambers with a floor space of 3.5 ft x 2 ft giving a total of 7 ft² or 0.65 m². There will be two birds in each chamber and meets the minimum requirement of .25 m² of floor space per bird. The height of each chamber is 2.85 ft. The floor will be made of standard commercial litter. The water supply and feeders will be delivered by Animal and Poultry Science who will look after the birds daily. Adequate lighting, heating and ventilation have been heavily scrutinized and are adequate for the amount of birds in the experiment. The environment enrichment provisions will be to industry standard to relay the most realistic results.

Section 7: Experimental and/or Animal Use Endpoint

7.1 Expected clinical conditions or abnormalities:

There should be no change in the conditions of the birds and no expected abnormalities. The experimentation will change nothing in terms of daily animal care as it is strictly only for observation of gasses generated by the animals.

7.2 Removal Criteria:

If any behavioral changes are noticed it will be brought straight to the attention of the Designated Veterinarian, as well as Dr. Ben Wood where they can make an informed decision on the outcome. Behavioral changes would be any signs of sickness. This would include lameness, not rising from the ground when people enter the room and for toenails decrease in vascularity when greater than 18 weeks.

7.3 When a health issue or injury unrelated to the experiment occurs, is regular veterinary care appropriate for the animals?:

Yes.

7.3.1 Please provide your explanation here:

No, we are strictly observing gaseous concentrations emitted from the turkeys under normal commercial conditions, therefore there is no variable that would disrupt experimentation such as use of anti-inflammatories.

Section 8: Procedures

8.1.1a) Species: turkeys
8.1.1b) Strain: Large White
8.1.1c) Quantity: 20
8.1.3 Drugs administered to this animal:
8.1.2 Procedures performed on this animal:

8.1.2a) Name of Procedure:

Other

8.1.2b) If you specified other, please provide further details:

Monitoring concentrations of greenhouse gasses emitted by the turkeys

8.1.2c) Extra information:

Each group of turkeys will have its gas exchange monitored continuously.

8.1.2d) Associated Distress or Pain Level:

B

8.1.2e) Procedure to be performed by:

Name:

Clayton Gionet.
8.1.2a) Name of Procedure:
Euthanasia - cervical dislocation (Please justify physical method below)

8.1.2c) Extra information:
All birds will be euthanized by cervical dislocation, either manually or with the assistance of Burdizzo clamps as per the Arkell Poultry SOP.

8.1.2d) Associated Distress or Pain Level:
C

8.1.2e) Procedure to be performed by:

Name:
Benjamin Wood, Animal And Poultry Science

8.1.2a) Name of Procedure:
Other

8.1.2b) If you specified other, please provide further details:
General Care

8.1.2c) Extra information:
Pertaining to the general husbandry of the birds. Feed and water will be provided ad libitum. Bedding will consist of wood shavings and be checked daily to ensure that the litter is dry and in good condition. Lighting of the pens will be for 14 hours of light and 10 hours of dark.

8.1.2d) Associated Distress or Pain Level:
B

8.1.2e) Procedure to be performed by:

Name:
Clayton Gionet

Name:
Animal and Poultry Science (ANNU), Animal &amp; Poultry Science

8.3 Specify the criteria that will be used to assess the level of analgesia / anaesthesia required.:
N/A

8.4 Give a sequential description of the use of animals in this teaching exercise or research project.:
The turkeys will be held in airtight ventilated plexiglass cages constructed to house a small group (5) of turkeys over a period of 1.5 weeks. They will be fed and supplied water by the technicians from Animal Biosciences. The animals involved in the experimental procedure will be of two separate groups; a high group, with previously calculated excellent feed efficiency, and a low group, with poorer feed efficiency. Outside air will be circulated into the plexiglass chambers and after removal of water vapor, a sub-sample of the expired air will go to inline analyzers for NH3, N2O, CO2, and CH4. Each group of turkeys will have its gas
exchange monitored continuously throughout the day. In addition, the gaseous composition of the room will be monitored for later calculation of the gas consumption (O2) and production of NH3, N2O, CO2, and CH4 by the turkeys.

The two chambers with the dimensions of 3.5 ft x 2.4 ft x 2.8 ft, will house two birds each, giving a total of four birds being tested on per day. The birds will be given random order and will be randomly selected for trials lasting 3 weeks. 10 birds of the high efficiency will be monitored at 4 birds per day (through random selection) for a period of 21 days. 4 birds will be selected at the start of each day and picked from the 10, after they will be monitored for 8 hours in a chamber. Once the testing is completed they will be removed from the chamber and placed back into an open air pen with the remaining birds that were not selected. The air exchange rate required is 60 h⁻¹ (Utah State University, 2010), which would give one air exchange for every minute of trial duration. This will provide adequate air exchange required for the health of the birds. The ventilation rate required is to be 20 cfm (J.E. Turnbull and H.E, Huffman, 2014) which will be delivered from exhaust fans on both chambers. If mechanical failure is detected on the fans, the birds will be removed from the chambers and the trial will be put on hold until mechanical failure is resolved.

8.5 Specify the frequency of observations and methods for monitoring the condition of the animals:
Animal Biosciences staff will take care of the birds daily, as well the graduate student will make daily trips to monitor the analyzers as well as the conditions present in the chamber. These checks will be done every hour for the duration of the trial day. The trials in the chamber will be 8 hours per day, the turkeys will then be moved to a open pen overnight. The pen will be located in an adjacent room in the Animal Science Building. The total length of stay for the turkeys will be 2.5 weeks for the trial and acclimation, this includes the 8 hour trials as well as the overnight stay and one week for acclimation. The birds will undergo euthanasia immediately proceeding the trials as detailed above.

8.7 List individuals who will be monitoring the animals:
- Clayton Gionet,
- Animal and Poultry Science (ANNU), Animal & Poultry Science

8.8 List groups who will be responsible for monitoring the animals:
Animal and Poultry Science

8.9 Explain refinements implemented to minimize pain, distress and/or discomfort to the animals, e.g. modified procedures:
The turkeys will be held in groups as to reduce stress from isolation. The gaseous levels of the greenhouse gasses will also be checked daily to remain within the daily allowable limits determined by the Ontario Government.

Section 9: Appendices

Review

ANIMAL CARE COMMITTEE APPROVAL

FOLLOWING APPROVAL, A PROTOCOL NUMBER WILL BE ASSIGNED. THIS NUMBER MUST BE USED WHEN ORDERING ANIMALS AND IT IS UNDERSTOOD THAT THESE ANIMALS WILL BE USED ONLY AS DESCRIBED IN THIS PROTOCOL.

THIS ANIMAL UTILIZATION PROTOCOL IS VALID FOR A PERIOD OF UP TO 12 MONTHS FROM THE DATE OF COMMENCEMENT.
THE ANIMAL CARE COMMITTEE WILL REQUEST ANNUAL REVIEWS FOR ALL PROTOCOLS.
THE ANIMAL CARE COMMITTEE CAN PROVIDE EXTENSIONS BEYOND THE 12 MONTH PERIOD, FOR A MAXIMUM OF 4 YEARS IN TOTAL.

MATERIAL TRANSFER AGREEMENTS (MTAS)

MTAs may be required to protect the rights of the parties involved in the exchange of biological materials for research purposes. For advice and assistance in this regard, please contact the Administrative Assistant, Business Development Office, 519-824-4120 ext 58878.

DECLARATION

THIS ANIMAL UTILIZATION PROTOCOL ACCURATELY DESCRIBES ALL THE PROPOSED ANIMAL USE.
IT WILL BE KEPT CURRENT AND WILL BE MODIFIED ONLY AFTER OBTAINING THE APPROVAL OF THE ANIMAL CARE COMMITTEE.

ALL PROCEDURES WILL BE CARRIED OUT BY PERSONNEL LISTED IN Q89 WHO ARE TRAINED AND COMPETENT IN USING APPROVED TECHNIQUES.

AN ANIMAL INCIDENT REPORT WILL BE FAXED TO THE DIRECTOR, ANIMAL CARE SERVICES, WITHIN 24 HOURS OF ANY UNEXPECTED PROBLEMS OR COMPLICATIONS INVOLVING ANIMAL HEALTH AND WELLBEING IN THIS STUDY. (AN ANIMAL INCIDENT REPORT IS AVAILABLE (HTTP://WWW.UOUGELPH.CA/RESEARCH/FORMS_POLICIES_PROCEDURES/ANIMAL.shtml) FOR THIS PURPOSE.)

ALL ANIMALS USED IN THIS RESEARCH/TEACHING PROJECT OR DISPLAY WILL BE CARED FOR IN ACCORDANCE WITH

- THE RECOMMENDATIONS OF THE CANADIAN COUNCIL ON ANIMAL CARE,
- THE REQUIREMENTS OF THE ANIMALS FOR RESEARCH ACT REVISED STATUTES OF ONTARIO, 1990, CHAPTER A.22,
- THE UNIVERSITY OF GUELPH ANIMAL CARE POLICY.

Provisos and Comments:

Note: Following ACS restructure, Dr. Anna Bolinder (x53110) has assumed the role of Designated Veterinarian for AUPs involving poultry, unless otherwise preferred by PI. The change has been made in your AUP.

Approval Dates:

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### Appendix E Stats

#### Test for Autocorrelation

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Appendix F Chamber and Exhaust System

Figure F-1 Environmental Chamber

Figure F-2 Mesh Covering for Exhaust from Chamber
Figure F-3 9 1/4" Circulation Holes on Chamber
Figure F-4 Cut out View of Fan Box Showing Fan Inside
Figure F-5 Top View of Enclosed Fan Box
Figure F-6 Top View of Iris Damper
Figure F-7 Side View of Iris Damper
Figure F-8 Iris Damper Showing Size Selection, adjusting a Bolt on Damper Opens and Closes Damper to Desired Radius
Appendix G Facilities

Figure G-1 Drinking System
Figure G-2 Wider View of High Efficiency Penning Room

Figure G-3 View of Low Efficiency Pen, The Drinker in the Back is from the High Efficiency Pen
Figure G-4 View of Drinker and Feeder in Low Efficiency Pen