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APPENDIX B TO FIELD SERVICES SUBMISSION

Alberta Agriculture and Forestry

STRATEGIC RESEARCH AND DEVELOPMENT PROGRAM
FINAL REPORT

INSTRUCTIONS:

- This report **must be a stand-alone report**, *i.e.,* must be complete in and of itself. Scientific articles or other publications cannot be substituted for the report.
- A signed electronic copy of this report must be forwarded to Alberta Agriculture and Forestry **on or before the due date**, as per the investment agreement.
- A **detailed, signed statement of expenses incurred** during the entire funding period of the project must be submitted along with this report (refer to section D.1.a for details).
- For any questions regarding the preparation and submission of this report, please contact the AF project manager assigned to your project OR Brian Karisa at brian.karisa@gov.ab.ca

Section A: Project overview

1. Project number: 2016E023R		
2. Project title: Impact of amended feedlot pen surface on cattle health and welfare, environmental and economic sustainability		
3. Project start date: 2016/02/01	**4. Project completion date:** 2019/01/31	
5. Research team information		
a) Principal investigator: (Requires personal data sheet [See Section E] only if Principal Investigator has changed since last report.)		
Name	**Institution**	**Expertise added**
Dr. Steve Hendrick	Coaldale Veterinary Clinic	Veterinary Epidemiologist
b) Research team members (List names of all team members. For each new team member, *i.e.*, joined since the last report, include a personal data sheet [See Section E]. Additional rows may be added if necessary.)		
Name	**Institution**	**Expertise added**
Dr. Greg Piorkowski	Alberta Agriculture and Forestry	Soil and Water Quality Research Scientist
Mr. Ike Edeogu	Alberta Agriculture and Forestry	Technology Development Engineer

Dr. Atta Atia	Alberta Agriculture and Forestry	Livestock Air Quality Specialist
Dr. Anne Huennemeyer	Alberta Agriculture and Forestry	Agricultural Economist
Dr. Karen Schwartzkopf-Genswein	Agriculture and Agri-Food Canada	Beef Cattle Welfare Scientist
Dr. Barry Olson	Alberta Agriculture and Forestry	Soil and Water Quality Research Scientist

Section B: Non-technical summary (max 1 page)

Alberta's *Agricultural Operation Practices Act* and Regulations details the requirements for constructing beef cattle feedlot pens with a protective layer or liner (including compacted clay) to prevent groundwater contamination. Although a relatively low-cost option for pen construction, clay substrates tend to create muddy conditions during spring melt or following precipitation events. Muddy conditions can in turn reduce feedlot productivity by increasing cattle energy expenditure and present adverse health outcomes to cattle primarily due to foot infections. Wet clay tends to admix with manure owing to compaction by cattle hooves, which leads to deterioration of the pen floor during manure scraping and pen cleanout, lowers the nutrient value of the manure, and ultimately increases pen and manure management costs.

Amending pen floors with roller compacted concrete (RCC) is one possible solution for stabilizing pen floors. Owing to its physical structure and impermeability, RCC is resistant to muddying and admixing with manure. This, in turn, may improve animal health outcomes and feedlot performance. However, the environmental benefits or tradeoffs of RCC, or other feedlot pen floor stabilization methods, have not been examined on a commercial scale. This study compared RCC and clay/mixed pen floors in terms of animal health and welfare and found that RCC floors led to reduced livestock morbidity, mostly due to less foot rot and digital dermatitis. RCC pens had 40% lower manure volumes due to less clay in the manure; reduced admixing of clay also improved the nutrient value of the manure. Gross estimates indicate RCC pens were associated with reduced greenhouse gas (GHG) emissions compared to clay pens. RCC yielded more run-off (18% of rainfall in RCC pens versus 7% of rainfall in clay pens) and higher nutrient export per runoff event, but had less seepage of mobile manure constituents into the soil profile. Based on a standardized feedlot pen, a normalized live weight gain of 556 pounds per head, and the specifics of this commercial feedlot, the study estimates a net present value of $5.60 per head associated with cattle pens retrofitted with RCC. Collectively, the learnings from this study suggest a positive net benefit is attainable by amending feedlot cattle pens with RCC. The inclusion of economic, environmental and social indicators in comprehensively assessing sustainable beef management practices is essential in providing a holistic perspective (benefits and trade-offs) on the net impacts for the sector.

Key considerations for producers wanting to install RCC:

- Catch basin dredging and water disposal will be more frequent and will require sound nutrient management planning to apply catch basin contents to adjacent fields.
- This study was unable to provide conclusive indication of the durability (useful life) of the RCC. Continued annual monitoring of RCC at the study site would be beneficial.
- Our cost-benefit analysis suggests that the economic performance of RCC technology is competitive and largely robust, relative to the site-specific, operational traits of the study feedlot.

Section C: Project details

1. Project team (max ½ page)

a) Describe the contribution of each member of the R&D team to the functioning of the project.

Dr. Steve Hendrick – Principle investigator, communication with the participating feedlot, over-seeing the research technician, and training of feedlot staff. Responsible for the collection and reporting of health, performance, behavioural and closeout data.

Dr. Atta Atia is a livestock air quality specialist with Alberta Agriculture and Forestry. He was responsible for assessing manure composition and quantity; and took the lead on the extension plan for this project.

Mr. Ike Edeogu (M.Sc., P.Eng.), Alberta Agriculture and Forestry. Responsible for research on ammonia and greenhouse gas emissions, and assessing RCC properties.

Dr. Greg Piorkowski - Water Quality Section, Alberta Agriculture and Forestry. Led the runoff and soil sampling components of the project. Analyzed and reported on runoff and soil data.

Dr. Barry Olson - Water Quality Section, Alberta Agriculture and Forestry. Advised on the runoff and soil sampling components of the project. Reviewed data and reporting.

Dr. Anne Huennemeyer is a research economist in the Economics and Competitiveness Branch of Alberta Agriculture and Forestry. She analyzed potential economic impacts (net on-farm benefits) of RCC technology in the context of the feedlot study.

b) Describe any changes to the team which occurred over the course of the project.

Dr. Karen Schwartzkopf-Genswein (Beef Welfare Scientist) provided consultation regarding the behavioural measures collected in this study.

Aung Moe (M.Sc., P.Ag.) was a lead analyst in life cycle assessment of agri-food production systems at Alberta Agriculture and Forestry. He helped develop the economic assessment model for the study.

2. Abbreviations:

Define ALL abbreviations used.
AAF - Alberta Agriculture and Forestry; ADG – average daily gain; COG – cost of gain; DOF – days on feed; F:G – feed-to-gain ratio; CV - coefficient of variation; DMI – dry matter intake; GHG - greenhouse gas; RCC - roller compacted concrete; SEM - standard error of the mean

3. Background (max 1 page)

Consumers more than ever are insisting that commercial livestock production practices are environmentally sustainable and protective of animal welfare. Given a growing global human population and, consequently, rising demand for high quality protein, the cattle feeding industry needs to continue to evolve and adapt to address new and existing animal welfare and environmental concerns. Furthermore, with advances in breeding and management, the size of cattle going to slaughter continues to increase (Canfax, 2019). In Alberta, feedlot pen floors are traditionally lined with compacted clay to meet provincial regulations (AG, 2017), but as cattle get heavier the need for more durable flooring options arises, without compromising animal welfare, food safety, the environment, or overall profitability.

One possible solution has been to amend pen floors using coal combustion byproducts, such as fly ash. Fly ash is a byproduct that has pozzolanic or self-cementing, properties owing to its small grain size and inherently large proportions of silicon- and calcium-oxides (Kalinkski et al. 2005). Fly ash when mixed directly with feedlot soils creates a cemented soil material that is reported to be 200 to 300% stronger than compacted clay soil (Greenlees et al., 1998). Bison steers fed in pens stabilized with fly-ash improved average daily gain (ADG) and feed-to-gain ratio (F:G) by 23% and 21%, respectively, due to less mud during spring thaw and summer rainfall events (Anderson et al., 2004). Much of the performance gains are realized from lower cattle morbidity and less energy expenditure by cattle having to navigate through muddy pens to access feed (Higgins et al. 2013). Previous field studies were conducted in small research feedlots making the investigation of pen re-surfacing on animal health difficult due to limited statistical power.

In addition to animal health and performance gains, paving feedlot pen floors is reported to lead to operational efficiencies and lower operating costs. Cemented floor surfaces create a hard interface between the pen surface and cattle manure, which aids in removing manure and reducing manure volumes (Higgins et al., 2013). Paved lots are also reported to promote runoff, leading to drier pens due to lower moisture retention and improved cattle health and weight gain by mitigating muddy conditions (Stout et al. 1999, Anderson et al. 2004, Pflughoeft-Hassen et al., 2004, Van Devender and Pennington 2004, Sweeten et al. 2006, Woodbury et al. 2013). Pflughoeft-Hassen et al. (2004) reported that runoff water quality was relatively similar between soil-based and paved pens, although pens cemented with fly ash tended to be higher in boron, attributed to the fly ash. On the other hand, nutrient loading, or the export of nutrients as a function of runoff volumes, tended to differ based on pen floor type based on rainfall simulation studies (Gilley et al. 2009). Given that soil and runoff water quality are influenced by within-pen heterogeneity (Miller et al., 2006), the rainfall simulation studies may not provide representative nutrient loading estimates according to conditions that prevail in commercial feedlots. In addition, the available literature does not include an assessment of the effects of paved pens on emissions of ammonia or GHGs.

Previous literature on the use of fly ash to stabilize pen floors generally evaluated soil-cement mixtures, created by mixing fly ash with on-site soil at research or demonstration sites. In Alberta, RCC containing fly ash as a partial substitute for Portland cement is increasingly being applied in feedlot cattle pens. RCC is a more affordable option than traditional concrete due to its blending of coal combustion byproducts as a cementing agent and drier consistency allowing for efficiencies in pen construction. In comparison to soil-cement, RCC may have a higher price owing to the use of screened aggregates rather than on-site soil. Anecdotally, RCC is thought to be a superior product due to more consistent blending and application, leading to a stronger and more durable material than soil-cement. However, to date, there have been no experimental or commercial research studies to support the use of RCC in cattle feedlots in Canada.

This study is the first comprehensive investigation to evaluate animal health, welfare, environment and profitability impacts associated with the amendment of pen surfaces in a commercial cattle feedlot in Alberta.

4. Objectives and deliverables (max 1 page)

a) State the original objective(s) and expected deliverable(s) of the project.

The original objectives of the study were to compare standard clay-floor pens to pen floors amended with fly ash-based RCC with respect to:

1. The health of cattle by assessing lameness rates and mud, lameness and tag scores, and behavioural indicators of welfare in the animals.
2. The durability of RCC in cattle feedlot pens.
3. The environmental effects of pen floor type on seepage and runoff water quality, ammonia emissions, and the amount and quality of manure.
4. The economic performance of retrofitting pen floors with RCC while accounting for differences in pen maintenance and manure handling costs.

The overall objective of this project is to determine if RCC pen floors in a feedlot will improve the health and welfare of confined cattle, reduce the environmental footprint, and result in a positive return on investment. The new knowledge generated from this study, via the great partnership between industry, public and private experts is expected to influence the future sustainability of the feedlot industry in Alberta. The cost of paving commercial feedlot pens can be substantial, and before more feedlots invest in this technology, therefore the research outcomes presented in this report will benefit the industry in making well-informed decisions.

b) Indicate any modifications to the objective(s) and deliverable(s) that occurred over the course of the project.

Objective 1. Hair cortisol was proposed as a behavioural indicator of animal welfare. Unfortunately, too few hair samples were collected (based on previous analyses) and it was determined that testing the existing samples would be a waste of funding if we had insufficient power to make a confident conclusion.

Objective 2. a) Assess changes in physical and chemical properties of RCC floor surfaces retrofitted in sixteen commercial feedlot cattle pens and a silage pad in 2015.

b) Measure the compressive strengths (physical property) of additional pen floor surfaces at the commercial feedlot, retrofitted with RCC in 2017 and 2018.

Objective 3. Compared GHG emissions from pens under different floor surface treatments.

5. Research design and methodology (max 4 pages)

Detailed descriptions and justifications for the multiple research designs and methodologies used in this study are included in the appendices to this report.

Study Location and Facilities:

This trial was conducted at a commercial feedlot in the County of Lethbridge with a feeding capacity of 12,000 head. In 2015, the feedlot re-surfaced 85% of the floor surface in 16 of its 50 feeding pens with RCC, hereby referred to as "RCC". The RCC pens spanned across two alleys with four adjacent pens per row (Figure A1). In another five pens, the back 50% of the pen floor surface was amended with RCC, and hereby referred to as "Mixed". The remaining twenty-nine pens were clay floor pens when the field study commenced in 2016, hereby referred to as "Clay". In October 2017, 11 pens were retrofitted with RCC by the commercial operation followed by another 7 pens in July 2018.

Thirty-two select RCC and Clay/Mixed pens at the feedlot were dedicated to addressing Objectives 1 and 4 over the duration of the study. Only the RCC pens were assessed under Objective 2. Runoff water and seepage water parameters (Objective 3) were evaluated with respect to the thirty-two select pens, while manure parameters and, ammonia and GHG emissions were evaluated based on all fifty feeding pens.

Study Animals:

Yearling heifers were used in this study to avoid sorting of animals at terminal implant to new pens potentially on different flooring. Heifers were housed in the thirty-two select pens for the duration of the study to facilitate comparisons between the RCC and Clay/Mixed floor surface treatments. Upon arrival at the feedlot, the cattle were systematically randomized into two replicate groups and then inducted using standardized protocols. All cattle were uniquely identified by a numbered ear tag and radio-frequency identification tag. Each replicate group was randomly assigned to either a RCC or Clay/Mixed pen.

A. Animal Health & Performance

Animal health events (processing, treatment or death loss), feeding data and body weight measurements were recorded using feedlot cattle management software. Crude and cause-specific morbidity and mortality rates and feedlot performance (dry matter intake (DMI), average daily gain (ADG); feed to gain ratio (F:G) were calculated by pen. Cattle were examined daily; any animals deemed sick or lame were diagnosed and treated by trained animal health staff according to veterinary protocols.

B. Lameness Scoring

Heifers that were identified as lame cattle were subjectively scored at the time of treatment based on a 5-point scale (Desrochers et al., 2001), with 0 signifying normal and 5, a non-ambulatory animal.

C. Meterology and Pen Condition

A weather station was setup at the feedlot to measure hourly and daily temperature (minimum, maximum and average), relative humidity, precipitation, and wind speed and direction. In addition, pen conditions were assessed once a week based on a 4-point scale, where a score of 1 indicated dry manure to a depth from 0 cm to 5 cm; 2 indicated wet manure to a depth from 5 cm to 19 cm; 3 indicated wet manure to a depth from 20 cm to 40 cm and; 4 indicated wet manure at a depth greater than 40 cm.

D. Tag Score

A subset of 10 cattle per pen in paired RCC and Clay/Mixed treatment pens were assessed weekly relative to the cleanliness of their hides (tag). A 4-point scale (Grandin, 2009), was used to score tag levels whereby a score of 1 signified a clean hide, possibly with some mud below the knees; 2, signified clean sides and belly, but noticeably muddy on legs above the knees; 3, clean sides, but caked mud noticeable on the belly and; 4, caked mud covering sides and belly.

E. Behaviour

In one out of every four paired RCC and Clay/Mixed treatment pens, a subset of 4 to 6 cattle per pen were fitted with an accelerometer tag (Sensoor tag, CowManager B.V., Netherlands) that automatically monitored how much time (hourly) the cattle spent eating, ruminating, being active, highly active or inactive over the feeding period. The tags were applied at induction and removed within 30 days of slaughter. The average time spent hourly exhibiting the various behaviours was contrasted across treatments.

The randomized block design of this study was intended to compare RCC vs Clay pens, and with no direct comparison of Clay and Mixed pens, it was decided to simply compare RCC vs Clay/Mixed pens. Mixed linear and logistic regression models were used to compare the effects pen floor treatment (RCC vs. Clay/Mixed) on the health and welfare outcomes described in sections A to E above.

F. RCC Properties

Four cores were extracted annually from randomly selected locations within six RCC pens and the silage pad in all three years. Intact cores were analyzed for compressive strength, density, percentage weight loss due to freeze-thaw cycling, while crushed cores were analyzed for total and leachable metal and non-metal elements. In 2018, eight additional cores were extracted from the pen surfaces retrofitted with RCC in 2017 and 2018. This latter set of cores were analyzed for compressive strength and density.

G. Runoff and Seepage Water Quality

Flumes were installed at the outlet end of the drainage swale in each of the eight rows of pens. Four of the rows comprised of RCC pens while the other four rows were Clay pens. Between 2016 and 2018, twelve precipitation events generated measurable runoff volumes in both Clay and RCC treatments and were included in statistical analyses. Ten events were sampled for water quality analyses, consisting of seven rainfall-runoff and three snowmelt runoff events. Generalized linear mixed models were used to assess the significance of effects of pen floor treatment (Clay or RCC) on runoff volumes, and water quality parameter concentrations and export. Floor treatment and event number were identified as fixed effects, and included as crossed factors. Random factors included the pen row and runoff event number.

Soil sampling proceeded through a repeated measures, randomized block design. Soil profile samples were collected annually (2016 to 2018) in three RCC and three Clay pens to test for temporal changes. In each pen, soil samples were collected from four depths (clay liner and three depths below the clay liner) at four sampling locations. Composites of the soil samples were analyzed for a range of chemical parameters. The significance of the floor treatments on soil quality was assessed using generalized linear mixed modelling. Fixed factors included floor treatment, soil depth, and year of sampling, while pen number was treated as a random effect.

H. Manure Composition and Quantity

Manure scraping and removal from the pens at the study site typically occur twice a year, in spring and fall. The amount of manure removed from independent RCC and Clay treatment pens were monitored over 3 years (2016 to 2018).

In addition, composite manure samples were collected from RCC and Clay treatment pens in 2017 and 2018. All manure samples were stored in a freezer until they were shipped to the testing laboratory (Central Testing Laboratory, Winnipeg, MB) for analysis. The samples were analyzed for several physical and chemical parameters.

The manure composition and quality data were analyzed using General Linear Models (GLM)***.*** The model tested the effects of feedlot pen surface (clay or RCC) on the manure physical and chemical properties.

I. <u>Air Quality and GHG Emissions</u>
Ammonia (NH_3) emissions were obtained from randomly selected sampling locations in pens under the three floor treatments, Clay, Mixed and RCC. Emissions were captured using closed, static flux chambers encasing acidified foam pads. Extracts from the foam pads were analyzed for NH_3 concentration. Manure samples obtained from the respective NH_3 sampling locations were analyzed for moisture content.

GHG samples were collected simultaneously from independent, randomly selected sampling locations during NH_3 sampling The air samples were analyzed for concentrations of three GHGs, nitrous oxide (N_2O), methane (CH_4) and carbon dioxide (CO_2). Manure samples from the respective GHG sampling locations were analyzed for moisture content.

The effects of the three floor treatments, manure moisture content and ambient air temperature data on NH_3, N_2O, CH_4 and CO_2 emissions, were analyzed statistically using the Kruskal-Wallis and Wilcoxon rank sum tests, and simple and multiple regression models.

J. Economics - Cost Benefit Analysis
A multi-year *benefit-cost framework* was used to capture the annual net benefits over a 20-year life span, associated with the investment in feedlot pens retrofitted with RCC. The framework was also used to assess the economic feasibility (Net Present Value, NPV), minimum payback period and the internal rate of return (IRR) at a standard discount rate of five per cent per year (supplemented by analysis of three and five per cent per year), as well as analyze the sensitivity of the economic outcome to changes in single parameters.

The economic analysis focusses on *on-farm* economics of RCC pen flooring while public *off-farm* benefits are not explicitly valued. Moreover, as cattle are typically marketed under different risk management strategies, comparing total revenue was not advisable. Instead, we tailor the economic approach to capture all efficiency gains from RCC technology in terms of overall cost savings (production costs, manure management and pen maintenance). The base unit of the NPV investment analysis is the average square footage of the experimental clay pen with approximately 35,000 ft^2 in size. The RCC replacement area is 70%, (i.e., 25,000 ft^2), and each pen holds 260 animals for an average of 175 days on feed (DOF). The feedlot operation's occupancy rate averages 90 per cent, leading to a cattle turnover of 1.88 turns per year. On average, this renders approximately 489 animals per pen per year and a total live weight gain of 271,528 pounds per pen per year (assuming a weight gain of 556 lbs/head).

6. Results, discussion and conclusions (max 8 pages)

Detailed results, including tables and figures, discussion and conclusions with respect to the following sub-sections (A to J), are included in the appendices to this report.

A. Animal Health and Performance:
A total of 42 pens of yearling heifers were enrolled in this study (Table A1). The average weight of these heifers arriving at the feedlot was 850 lbs (standard deviation = 50 lb). Morbidity rates were higher in the Clay/Mixed pens (40%) than the RCC pens (27%), which is mostly attributable to increased foot rot treatments (Table A2). All pen types had the same maintenance schedule for bedding, scraping and manure removal. The increased average live weight at slaughter for cattle in RCC pens (1445 lb) versus clay/mixed (1425 lb) is most likely due to the additional days on feed (DOF) in the former (182 days) compared to the latter (179 days). Although not significantly different (p=0.10),heifers in RCC pens had a higher average daily gain of 3.23 lb per day compared to 3.17 lb per day in the Clay/Mixed pens, which accounted for a normalized difference in live weight at slaughter of 10.9 lb between treatments. No difference was found in average daily dry matter intake (p=0.51), or F:G (p=0.10), but heifers in RCC pens had a lower F:G ratio (7.02) than heifers in Clay/Mixed pens (7.14). Overall, the RCC treatment reduced infectious lameness and morbidity, but did not significantly improve cattle performance under the environmental conditions of this study.

B. Lameness Scoring:
No differences were observed in average lameness scores between the two floor treatments (Table A2). Early detection and treatment of lameness (predominantly foot rot and digital dermatitis) by the feedlot may have influenced the low average scores.

C. Pen Condition:
Table A2 also shows the average mud depth score associated with the RCC treatment (1.18) was significantly less (p<0.01) than the Clay/Mixed pen score (1.13). The practical significance of such a small difference in mud depth score could be debated, but this may help explain the reduced incidence of foot rot and digital dermatitis morbidity observed in the RCC pens. With near or below-normal precipitation observed throughout this study, it is likely that in years when increased precipitation events are experienced, there will be a greater difference in average mud depth score.

D. Tag Score:
The difference in average tag scores (Table A2) between treatments were similar to mud depth scores, with a significantly lower (p<0.01) tag score for the RCC treatment (1.20) versus the Clay/Mixed treatment (1.25). The significance of the small difference in tag score between treatments is unknown because data on carcass dressing percentage at slaughter, and subsequently the effect of tag score on yield, was not available for all the treatment pens.

E. Pen Behaviour:

Behavioural data for seventeen heifers in four RCC pens and sixteen heifers in four Clay/Mixed pens are shown in Table A3 .The average minutes per hour the cattle expressed various behaviors and activity levels during a feeding period were not significantly different ($p>0.05$) between treatments. The small sample size of the datasets and variability in the expression of these behaviors may explain why no statistical differences ($\alpha = 0.05$) were found. Tags were applied to animals from four other pens, but unfortunately due to tag loss (misapplied) and power failure to the router, there was a limited number of observations from both treatment groups. Subsequently, the latter dataset was excluded from the final analysis.

F. RCC Properties:

The compressive strengths, densities and frost weathering losses of the RCC cores are summarized in Tables B1, B2 and B3, respectively. Mean compressive strengths of the feedlot pens and silage pad retrofitted with RCC in 2015 ranged between 10.6 MPa and 16 MPa, compared to 19.9 MPa and 26.5 MPa, for the pens retrofitted with RCC in 2017 and 2018, respectively. The highest variability (CV = 55%) in compressive strength was observed in pens in C-row compared to B-row (CV = 28%), suggesting improvements in RCC installation practices with increasing experience.

Mean core densities of the RCC installed in 2015 ranged between 2216 $kg \cdot m^{-3}$ (C-row) and 2328 $kg \cdot m^{-3}$ (silage pad). Mean densities of the RCC installed in 2017 and 2018 were 2255 $kg \cdot m^{-3}$ and 2276 $kg \cdot m^{-3}$, respectively. RCC density in the pens and silage pad were more uniform (less variable) compared to compressive strength, with CV values ranging between 0.7% and 2.1%. Interestingly, there seems to be a decline in density with time in all RCC floor surfaces installed in 2015 (Figure B3).

Freeze-thaw analysis was based on a limited number of samples extracted from some of the pens and silage pad retrofitted with RCC in 2015. Again, the third set pens retrofitted with RCC in 2015 seemed to indicate the highest mass loss due to weathering after sequential exposure to 10, 20 and 30 freeze-thaw cycles.

Concentrations of total metal and non-metal elements are summarized in Table B4. The concentrations of boron, calcium, iron, magnesium and manganese were higher in crushed RCC samples from the pens and silage pad retrofitted with RCC in 2015 versus manure samples from the feedlot pens. In contrast, the concentrations of copper, molybdenum, phosphorus, potassium, sodium, sulphur and zinc were higher in the manure. All total metal and non-metal concentrations seemed to be well below regulatory levels. Leachable elemental concentrations were compared against Alberta Tier 1 Soil and Groundwater Remediation Guidelines for Agricultural Soil to contextualize the results; however, the definition of risk for agricultural soil does not directly transfer to feedlot pen floors or manure collected from commercial feedlots. That said, all concentrations of leachable metal and non-metal elements (Table B5) were below Alberta Tier 1 guidelines in the RCC material and manure, except for the case of zinc in manure, which marginally exceeded the guideline value. Boron, which is enriched in fly ash, could not be directly compared to the guideline value because the guidelines are based on extractable boron, which was not analyzed for in the RCC or manure samples.

G. Runoff Water Sampling:

Meteorological data collected on the study site was compared to long-term normal (1961 – 2016) estimates from the Iron Springs Alberta Climate Information Service (ACIS) station, located 6.2 km from the site. In general, the monthly average temperatures conformed with the long-term normal. However, high- and low-temperature anomalies were periodically encountered (Figure C1). Monthly accumulated precipitations exceeded long term normals in July through to October, 2016, but were substantially lower in May through to September, 2017, December, 2017 through to January, 2018, and May through to June, 2018. Storm events that generated measurable runoff volumes were relatively common; with one 1:5-year storm event and other events less than or equal to 1:2 year events (Table C1).

The runoff coefficient (proportion of runoff volume to precipitation volume) was significantly greater ($p<0.01$) for RCC pens in comparison to Clay pens. On average, RCC alleys had a runoff coefficient of 0.18 while the Clay alleys had a coefficient of 0.07, meaning 18% and 7% of the precipitation was transported as runoff, respectively. On a concentration basis, the concentrations of solids and nutrients in the runoff leaving the RCC alleys was comparable to that of clay alleys (Table C2). However, concentrations of heavy metal parameters were significantly higher in the runoff from Clay alleys in comparison to RCC alleys (Table C2), likely due to the entrainment of clay (and associated metals) in the runoff. Higher runoff volumes in RCC alleys led to significantly higher event-based export of solids and nutrient parameters (Table C3). For most heavy metal parameters, the export coefficients were relatively comparable between the Clay and RCC alleys, as a result of the lower runoff volumes emitted from Clay alleys. However, the export of heavy metals enriched in manure, such as copper and zinc, remained elevated in the RCC alleys.

RCC pens had significantly lower concentrations of total available nitrogen, ammonia-nitrogen, chloride and electrical conductivity in the clay liner overlying the native soil, in comparison to the clay pens (Table C4). Most other soil quality constituents demonstrated significant differences with increasing soil depth. The clay liner was generally higher in the concentration of the constituents except for total organic carbon, total nitrogen and available phosphate-phosphorus, which were higher in the native topsoil underlying the clay liner (Table C4). In general, the effect of time on soil quality was not significant, except in some years where interactive effects with soil depth were observed. Since there was no consistency in the direction, magnitude or trend in relevant parameters, the effect of time is not presented in Table C4. Overall, RCC appeared to mitigate the transport of mobile constituents, such as nitrogen and chloride, and did not lead to adverse influences on soil quality owing to the presence of fly ash in the RCC. Based on these outcomes, additional studies are recommended to test the hypothesis that RCC in feedlot pens is protective of groundwater impacts.

H. Manure Composition and Quantity

Manure nutrient composition (N-P-K) from the clay pens were found to be comparable with those reported in published literature (Table D2); however, the nutrient composition of manure collected from RCC pens tended to be greater than reported values. Results of manure analysis are summarized in Table D3. Manure from Clay pens had a significantly ($p<0.01$) higher ash content (39.5%) compared to manure from RCC pens (22.8%) likely due to clay admixed with manure in the former. This result aligns with previous reports that found manure collected from soil-surfaced pens contained greater ash content than that collected from fly ash-stabilized pens (Woodbury et al., 2007; Sweeten et al., 2013). The inclusion of clay, approximated by ash content, is likely to reduce the nutrient value of the manure. In this study, concentrations of N, P, K were 27%, 30% and 36% greater in RCC pens compared to Clay pens (Table D3). Concentrations of heavy metals, such as iron, manganese, molybdenum were higher in clay-surfaced pens, likely as a result of clay admixing with manure in the pen. Woodbury et al. (2013) also concluded that manure collected from pens surfaced with cementitious material had more nutrients and was more energy dense than soil-surfaced pens. Due to the lower ash and higher nutrient content, manure from RCC pens is likely to generate higher agronomic value than manure from clay pens.

Manure Hauling

The mass of manure hauled from RCC, Clay and Mixed pens throughout the study are presented in Table D4. The average amount of manure removed from Clay, Mixed and RCC pens are 8.2, 5.7 and 4.9 kg/head-day, respectively, demonstrating more manure was being hauled from Clay pens compared to Mixed and RCC pens. Kissinger et (2007) reported that, on average, 7.2 kg manure was removed per animal per day from soil-surfaced pens. The results indicated that about 40% less manure per head-days was collected from RCC pens compared to clay pens. This result does not agree directly with the ash content of manure samples collected from the study pens, where ash content on a dry matter basis in Clay pens were on average 16.5% greater than RCC pens. Owing to the reduced volumes of manure collected from RCC pens, costs associated with manure hauling and disposal will be much lower for RCC pens compared with Clay pens.

I. Ammonia and GHG Emissions:

The distribution of NH_3 emissions associated with the three pen floor treatments were positively skewed (Figure E3). Comparatively, there were no statistical differences in median ammonia emissions between the floor treatments (Table E1). The results of simple and multiple regression analyses on the possible effects of manure moisture content and ambient air temperature on NH_3 emissions (Table E2) signified no influence of both parameters, either individually or interactively, on NH_3 emissions in the three floor treatments.

Similar to NH_3 emissions, the distribution of N_2O, CH_4 and CO_2 emissions associated with the three pen floor treatments were positively skewed. Statistically, median N_2O and CH_4 emissions were significantly lower from the RCC pens compared to the Mixed and Clay pens. On the other hand, there were no statistical differences in median CO_2 emissions among the three pen floor treatments. Collectively, it appears that the Clay pens provided conducive micro-environments that supported anoxic biological activity, favouring N_2O and CH_4

production. The results of simple and multiple regression analyses to evaluate possible influences of manure moisture content and ambient air temperature (Tables E5, E7 and E9) indicated no effects of the two parameters on N_2O and CH_4 emissions in all pen floor treatments, nor CO_2 emissions in the Clay and Mixed treatment pens. However, there was tendency that manure moisture content reduced CO_2 emissions from the RCC treatment pens.

J. Economics (For further detail of the economic analysis see appendix F)

Estimated Benefits and Costs of RCC Flooring

Empirical data shows a numerical increase (p=0.10) in ADG for cattle on RCC flooring versus cattle on Clay flooring. This productivity gain is captured as a cost differential per pound gained in the magnitude of 1.9 cents per pound ($11 per head), and translates to approximately $5,211 pen per year in terms of reduced production costs. This cost saving is supplemented by reduced manure management cost of approximately $2,105 per year, and reduced clay replacement costs of approximately $1,294 per year and comes to a total of just $6,610 per pen per year. This is contrasted by total investment costs of just under $50,000 per pen ($2 per square foot), and approximated maintenance costs of 1% per year.

Net Present Value

Given our assumptions, the net present value (NPV) per pen is positive and just under *$55,000 per pen over a 20-year-period*. The payback time for the base case scenario ranges between six years (3% discount rate) and 7 years (5% and 7% discount rate). Payoffs to this investment under the current assumptions are high: The internal rate of return (IRR) of the investment is approximately 15% per year. The calculated NPV values translate to an average *NPV of $5.60 per animal* ($7.45 per head and $4.15 per head at 5% and 7% discount rates, respectively). This is equivalent a total cost of gain difference of $0.0134/lb, $0.0101/lb and $0.0075/lb (for standardized total weight gain of 556 pounds) at 3%, 5%, and 7% discount rates, respectively. Cost recovery may occur within approximately 5 years. Results improve when we assume that all parameter values are defined cumulatively more favorable (better case scenario); however, results decline when assumptions are less favorable.

Sensitivity to Single Variables

The economic performance of RCC flooring is robust and competitive, but sensitive to changes in single variables. If we assume, for example, a lack of noticeable difference in production costs between floor types (i.e., cost of gain differential shrinks towards zero), RCC flooring remains competitive as long as the cost of gain differential exceeds approximately $2.13 per head (0.36 cents per pound). Likewise, investment costs would have to double to $4.00 per square foot, all else held equal, to render RCC not competitive as a pen floor material, or occupancy rates would have to drop significantly. In terms of manure differentials between Clay and RCC, our economic analysis suggests that NPVs remain about zero even if there is no manure differential at all. Naturally, if costs associated with Clay flooring (manure hauling or clay replacement) drop, the RCC floor type tends to be less competitive than the standard Clay flooring. While the economic performance of RCC is encouraging, it must be noted that generalizations for the entire industry are difficult, as results are site-specific of the experimental feedlot.

NB: Tables, graphs, manuscripts, etc., may be included as appendices to this report.

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8. Benefits to the industry (max 1 page; respond to sections *a)* and *b)* separately)

a) Describe the impact of the project results on Alberta's agriculture and food industry (results achieved and potential short-term, medium-term and long-term outcomes).

For confinement feeding in Alberta to remain sustainable, there is a need to reduce animal welfare and environmental concerns while improving feedlot operation efficiencies. RCC applied to feedlot pen floors is one possible options to address some of these concerns. RCC pen flooring potentially improves operational feedlot performance by improving livestock health and welfare, improving pen cleaning operations, and reducing or eliminating pen floor repair costs. Based on the results of our study, average daily gain may potentially increase in the order of about 5-10%. The use of RCC flooring over clay was found to measurably reduce greenhouse gas emissions and percolation of manure constituents to subsurface soils, but had measurable increases to runoff volumes (18% precipitation as runoff vs. 7%), and nutrient export. Improved animal welfare and greenhouse gas reductions may enhance market access opportunities; however, producers must be aware of and appropriately manage the environmental offsets of RCC pen flooring.

b) Quantify the potential economic impact of the project results (*e.g.,* cost-benefit analysis, potential size of market, improvement in efficiency, etc.).

Our cost-benefit analysis suggests that the economics of RCC flooring is competitive and robust, albeit sensitive to cumulative changes in key variables that influence the economic viability of RCC. Naturally, if costs associated with clay pen maintenance (such as manure hauling or clay replacement) drop, RCC flooring would be less competitive. Using feedlot demographics and the site-specific results of our study of a commercial feedlot, we calculate industry-wide benefits of RCC technology at approximately $65,078 per year for every 1% of Alberta's total feedlot population (equivalent to approximately 12,000 head, Canfax Statistical Briefer, 2019) on RCC pen flooring. The economic analysis focusses on *on-farm* economics of RCC flooring. In addition, a benefit-cost framework is capable of capturing public *off-farm* benefits, if any, such as potential reductions in GHG emissions and water pollution, animal welfare improvements or a higher nutrient value of RCC feedlot manure. If these benefits are measurable and if markets for them exists, feedlot owners can capitalize on these values in form of market revenues, and incorporate them into their annual benefit stream. Moreover, each year, feedlot operators in Alberta truck large volumes of clay into their pens to fill damaged, low lying sections of the pen floors created by heavy cattle traffic in those areas and manure clean out events. In extremely wet years, the demand for clay and maintenance requirements increases significantly as the damage to the pen floor escalates, subsequently demanding more time and increased repair costs for operators. The dependence on clay for feedlot pens also presents external environmental sustainability issues, wherein clay must be mined from separate land areas that require additional environmental management. By comparison, with the presence of a hard RCC floor, heavy equipment will be able to enter the pens earlier in the spring under wetter conditions to remove manure, no soil will be mixed with the manure thereby reducing the volume of manure, which in turn will reduce the volume and cost of manure hauling, and reliance on external soil resources will be prevented. Not included in the economic analysis (due to lack of measurable effects) is the increased likelihood that producers using RCC pen floors will have to pump and dredge their catch basins more frequently. Increasing the frequency of catch basin management will add costs to a feedlot operation, but these costs have yet to be quantified.

The authors maintain that the production, economic and environmental performance of RCC flooring as described in this study must be understood in the specific context (management practices; pen sizes, stocking densities, topography, etc.) of the feedlot operation that hosted the experiment. A generalization of the findings to the wider feedlot sector in Alberta requires caution, and will depend on whether or not these management practices are considered representative of Alberta feedlots. The results of this study, therefore, are an indication of direction rather than of magnitude, and enterprises must be advised to calculate potential impacts of retrofitting their feedlot floors on a case-by-case basis.

9. Contribution to training of highly qualified personnel (max ½ page)

Specify the number of highly qualified personnel (*e.g.*, students, post-doctoral fellows, technicians, research associates, etc.) who were trained over the course of the project.

One research technician was hired by Coaldale Veterinary Clinic to assist with data collection at the feedlot (mud and tag score pens of cattle each week; application of ear tags for behavioural monitoring; organizing the collection of manure samples; scheduling and facilitation of the greenhouse gas sampling).

Through the project works, two technicians from the Water Quality Section of Alberta Agriculture and Forestry were trained on the installation of flumes for runoff monitoring as well as interfacing automated water sampling equipment with water level sensors. The knowledge gained in this project can be applied in other circumstances warranting simultaneous measurements of runoff volume and water quality for assessing agricultural management practices on water quality.

A supporting team of technicians, scientists, engineers and subject matter specialists with the Environmental Stewardship Branch, Alberta Agriculture and Forestry were involved in this project. Two research assistants employed by the Coaldale Veterinary Clinic were stationed at the Farm Stewardship Centre in Lethbridge to assist with the research activities. The team of employees assisted with the research experiment design, pre-sampling preparatory activities, field sampling activities, post-sampling preparatory activities, and data analysis associated with the RCC properties, ammonia and GHG sampling and analysis, manure sampling and analysis, and meteorological station set up, monitoring and maintenance.

10. Knowledge transfer/technology transfer/commercialisation (max 1 page)

Describe how the project results were communicated to the scientific community, to industry stakeholders, and to the general public. Please ensure that you include descriptive information, such as the date, location, etc. Organise according to the following categories as applicable:

a) Scientific publications (*e.g.*, scientific journals); attach copies of any publications as an appendix to this final report

Manuscripts have been prepared to summarize and publish each of the study components in peer-reviewed journals such as the Canadian Journal of Animal Science and Journal of Environmental Quality or Agriculture, Ecosystems and Environment.

b) Scientific presentations (*e.g.*, posters, talks, seminars, workshops, etc.)

Two presentations have been given at the AAF Manure Management Meetings held in Lethbridge – Jan 2016 and Jan 14, 2019. The first presentation outlined our study plans and the most recent presentation provided results to date.

c) Industry-oriented publications (*e.g.*, agribusiness trade press, popular press, etc.); attach copies of any publications as an appendix to this final report

Findings have been published in two articles by the Western Producer (Vol. 97 No. 5 p. 48; Jan. 31, 2019):
Roller compacted concrete catches on in prairie feedlots
https://www.producer.com/2019/01/roller-compacted-concrete-catches-on-in-prairie-feedlots/

Concrete blend new in feedlots
https://www.producer.com/2019/01/concrete-blend-new-in-feedlots/

d) Industry-oriented presentations (*e.g.*, posters, talks, seminars, workshops, etc.)
Presentation made at Alberta Cattle Feeders Association Annual General Meeting in Red Deer, March 12, 2019

e) Media activities (*e.g.*, radio, television, internet, etc.)
Industry Factsheets: A 2-4 page fact sheet will be prepared that is suitable for posting on producer accessible websites (Alberta Agriculture and Forestry)

f) Any commercialisation activities or patents
No patents or commercialized activities are anticipated from this project.

The information for this project will be disseminated according to the extension plan in Appendix G. Alberta Agriculture and Forestry is dedicated to the extension of beneficial management practices (BMPs) that promote environmental sustainability by the agricultural sector in the province. In addition, the Ministry financially supports the adoption of BMPs (such as the one proposed in this study) through its Canadian Agricultural Partnership Federal-Provincial initiative. Upon the conclusion of this study, assuming the net benefit of resurfacing feedlot pen floors with RCC is positive, various specialists from across Alberta Agriculture and Forestry will promote the adoption of the BMP via factsheets (outlining its attributes, limitations and specifications for implementation), seminars, workshops, field days, funding programs and one-on-one consultations with confined feeding feedlot operations in the province. Research efforts will also continue in order to optimize the BMP and further reduce pen floor resurfacing costs for the feedlot industry.

Fill out the table below with the total number of each performance measure:

Number of scientific publications / presentations	5 tentative publications
Number of industry communications	2
Number of patents / licenses	0

Section D: Project resources

1. **Statement of revenues and expenditures:**
   a) **In a separate document certified by the organisation's accountant or other senior executive officer, provide a detailed listing of all cash revenues to the project and expenditures of project cash funds.** Revenues should be identified by funder, if applicable. Expenditures should be classified into the following categories: personnel; travel; capital assets; supplies; communication, dissemination and linkage (CDL); and overhead (if applicable).
   b) **Provide a justification of project expenditures and discuss any major variance (*i.e.*, ± 10%) from the budget approved by the funder(s).**

The project was dependent upon technical personnel to get the samples and data collected at the feedlot. Three years of data collection (two were initially proposed) were required to get the necessary samples or observations which increased our personnel expenses. This was an added expenditure to the project, but completion of this aspect of the project would not have been possible without the extra help. Hair samples for cortisol testing were collected on a subset of animals, but it was deemed to few to attempt assessing the cortisol levels. This did save the project $20,000 in supplies for testing of the samples. The CDL for this project is being covered in-kind by AAF.

2. Resources:

Provide a list of all external cash and in-kind resources which were contributed to the project.

Total resources contributed to the project		
Source	**Amount**	**Percentage of total project cost**
Alberta Agriculture and Forestry	$233,452	15.6%
Other government sources: Cash	$0	0%
Other government sources: In-kind	$455,815	30.5%
Industry: Cash	$0	0%
Industry: In-kind	$805,721	53.9%
Total Project Cost	$1,494,988	100%

External resources (additional rows may be added if necessary)		
Government sources		
Name (no abbreviations unless defined previously)	Amount cash	Amount in-kind
Alberta Agriculture and Forestry	$233,452	$435,000
Industry sources		
Name (no abbreviations unless defined previously)	Amount cash	Amount in-kind
Participating feedlot		$800,000
Coaldale Veterinary Clinic		$5,720

Section E: Research Team Signatures and Employers' Approval

1. Personal data sheet(s) for NEW Principal Investigator and/or team members.

Complete a personal data sheet for any NEW Principal Investigator **and/or** ***research team members. Any NEW Principal Investigator and/or team members MUST sign this form, as well as an authorised representative from his/her organisation of employment.*** (Duplicate this sheet as required)

NB: If there is a NEW Principal Investigator, please advise the funders' representative of this change in writing in addition to filling out this personal data sheet. This will allow the funder(s) to make the necessary administrative changes to the project file.

NB: Existing Principal Investigator and team members DO NOT need to complete a new form.

<table>
<tr><td colspan="2">Name: Dr. Anne Huennemeyer
Dr./Mr./Ms./Mrs. Last First</td></tr>
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University of Guelph (2001)</td></tr>
<tr><td colspan="2">Publications and Patents:</td></tr>
<tr><td>Number of refereed papers:
Relevant patents obtained:</td><td>Conference proceedings:
Other relevant publications from the past 5 yr:</td></tr>
<tr><td colspan="2">Other evidence of productivity (e.g., administrative roles, grants held, awards received, etc.):</td></tr>
<tr><td colspan="2">NEW Team Member</td></tr>
<tr><td>Name:</td><td>Title/Organisation:</td></tr>
<tr><td>Signature:</td><td>Date:</td></tr>
<tr><td colspan="2">NEW Team Member's Employer's Approval</td></tr>
<tr><td>Name:</td><td>Title/Organisation:</td></tr>
<tr><td>Signature:</td><td>Date:</td></tr>
</table>

2. **The principal investigator and an authorised representative from his/her organisation of employment MUST sign this form.**

Research team members and an authorised representative from their organisation(s) of employment MUST also sign this form.

Signatures may be scanned and submitted electronically. Original signatures should be retained by the PI and MAY be requested by the funder(s) in the future

By signing as representatives of the principal investigator's employing organisation and/or the research team member's(s') employing organisation(s), the undersigned hereby acknowledge submission of the information contained in this final report to the funder(s).

Principal Investigator

Principal Investigator	
Name: Steve Hendrick	**Title/Organisation:** Veterinary Epidemiologist, Coaldale Veterinary Clinic
Signature: [redacted]	**Date:** April 29, 2019
Principal Investigator's Employer's Approval	
Name: Phil Klassen	**Title/Organisation:** Managing Partner, Coaldale Veterinary Clinic
Signature: [redacted]	**Date:** April 29, 2019

Research Team Members (add more lines as needed)

1. Team Member	
Name: Ike Edeogu	**Title/Organisation:** Technology Development Engineer, Environmental Stewardship Branch, Ministry of Agriculture & Forestry
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3. Team Member	
Name: Greg Piorkowski	**Title/Organisation:** Watershed Research Scientist/Irrigation and Farm Water Branch, Alberta Agriculture and Forestry
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Team Member's Employer's Approval	
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4. Team Member	
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Team Member's Employer's Approval	
Name: Philippa Rodrigues	**Title/Organisation:** Director, Economics and Competitiveness Branch, Alberta Agriculture & Forestry
Signature: [redacted]	**Date:** April 25, 2019

Section F: Suggested reviewers for the final report

Provide the names and contact information of four potential reviewers for this final report. The suggested reviewers **should not be current collaborators**. The funder(s) reserves the right to choose other reviewers. Under *Section 34* of the *Freedom of Information and Protection Act FOIP)* reviewers must be aware that their information is being collected and used for the purpose of the external review.

Reviewer #1

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Position:	[redacted]
Institution:	[redacted]
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APPENDIX A: ANIMAL HEALTH, PERFORMANCE AND BEHAVIOUR

A.1. Abstract

A randomized complete block design trial was conducted in a commercial finishing feedlot in southern Alberta, Canada using yearling heifers (n = 5430; initial body weight 850 ± 50 lb; 380.9 ± 10.0 kg) to compare pen floors amended with roller compacted concrete (RCC) vs traditional compacted clay floors (Clay) on animal health, performance and behavior measurements. Heifers on RCC floors had significantly reduced morbidity rates due to lower treatments for foot rot ($P = 0.02$), and digital dermatitis while mortality rates did not differ. Animals housed on RCC tended to have improved ADG and F:G. No differences were found in time spent eating, ruminating and level of activity over the feeding period, however, mud and tag scores were reduced in RCC pens. Overall, pen floors amended with RCC appears positive for animal health, welfare and performance.

A.2. Objectives

The purpose of this field study was to compare standard compacted clay-floor pens to pen floors amended with roller compacted concrete with respect to morbidity, mortality, lameness rates, mud depth, lameness and tag scores, and time spent eating, ruminating and level of activity (active, highly active and not active). The performance of cattle (average daily gain and dry matter conversion) will also be compared by pen floor type.

A.3. Materials and Methods

A.3.1 Study Facility

This trial was conducted at a commercial feedlot in southern Alberta, Canada with a one-time feeding capacity of 10,000 head. The animals were housed in open pens with 20% porosity wood-fence windbreaks, heated automatic waterer and a concrete feed bunk within the fence line facing a common feed alley. Each pen held 250 to 300 animals. The hospital and treatment area of this feedlot was used to administer treatments and weigh animals. The hospital had a roof and concrete floor and was equipped with a hydraulically operated squeeze chute with weigh scale and chute side computer and health data management system (Fusion, SSG Fusion Ltd., Picture Butte, Alberta). Body temperatures were taken with an electronic thermometer (M750 thermometer, GLA Agricultural Electronics, San Luis, Obispo, CA).

Cattle were fed rations consisting of wheat and barley grain, corn and/or barley silage, and corn dried distiller grains with solubles. Vitamins, minerals and medicated feed ingredients were fed through a micro mixing machine (Micro Beef Technologies, Amarillo, TX). Diets were formulated to meet nutritional requirements of feedlot cattle, consistent with normal feeding protocols in the feedlot. Monensin sodium (44 ppm, 100% dry matter basis) was included in the ration throughout the feeding period to improve performance and control bloat and coccidiosis. Tylosin phosphate (11 ppm, 100 % dry matter basis) was included in the ration throughout the feeding period to reduce liver abscesses. Melengesterol acetate (0.45 mg/hd/day) was included in the finishing diet. All pens were fed their rations three times daily on an *ad libitum* basis using truck mounted mixers on load cells. Feed intake was recorded by pen, with feed from sick and chronic pens prorated back to the original lot of cattle. The dry matter content of the ration varied from starter rations (approximately 55% DM) to finishing rations (approximately 77% DM).

A.3.2 Study Animals

Eleven thousand and twenty eight (n = 11,128) crossbred yearling heifers approximately 12 to 16 months of age with an average induction weight of 850 lbs (386 kg) were used in this study. Yearling heifers were procured through the auction market system, backgrounding feedlots or directly off grass and shipped to the feedlot. Upon arrival at the finishing feedlot, yearling heifers were given a modified-live IBR, PI3, BRSV, and BVD type 1 & 2 vaccine[a], 8-way clostridial bacterin[b], ivermectin pour-on[c] and an anabolic implant[d]. All animals were uniquely identified with a numbered feedlot eartag and CCIA (Canadian Cattle Identification Agency) tag. Animals were put onto the study within 48 hours after arrival at the feedlot.

A total of 6 blocks (2 blocks per year; total of 12 pens) were selected for behavioural monitoring. In each of these pens, a subset of 4 heifers per pen were equipped with the CowManager ear tag sensor at induction. The sensor was mounted onto a blank radio frequency identification tag. Data from the sensor were sent wirelessly through a plug and play router to a coordinator in the feedlot office and made available through a web-based application (Bikker et al., 2014). Agis Automatisering BV provided raw hourly data for the ruminating, eating, not active, active and high active behaviors for all tagged heifers. The sensor detected and identified ear and head movements and through algorithms classified data as ruminating, eating, not active, active, and high active behaviors.

A.3.3 Experimental design

A randomized block design was used. Each block consisted of two pens as they were filled. A total of 42 pens or 21 blocks were created. The sample size used here is typical for commercial feedlot trials when assessing pen-level interventions. Pens within a block were randomized to one of two treatments: 1) housed in a pen with compacted clay flooring, or 2) housed in a pen with amended flooring of roller compacted concrete. Both pens had similar animal density.

A.3.4 Animal Allotment

Experimental animals were selected from large groups of animals arriving at the feedlot from March 16, 2016 to May 2, 2018. As new cattle were presented for processing, the yearling heifers within each arrival processing group were randomly assigned to one of two treatment groups using systematic randomization in groups of 2 head. Once the two groups were formed, they were each weighed using a ground scale to calculate the total weight of the group (shrunk by 4%). Each group was then processed, and individual animals weighed in the processing chute. The scale in the processing chute was verified with a standard weight and calibrated as necessary prior to processing. After every 25 head, the scale was tared to zero. Yearlings from the two treatment groups were penned separately. Once two pens were full (approximately 250 to 300 animals in each pen). Each pen was an experimental unit and each group of two pens represented a block. Animals were moved to their home pen and maintained as a unit for the duration of the trial, which was from induction processing until slaughter. Animals from the same treatment were sent together to slaughter and a total live weight of each shipment was measured over a ground scale with a 4% shrink.

A.3.5 Observations

Any animals appearing "sick" based on subjective parameters such as general appearance and attitude, gauntness, reluctance to move, lameness, separation from group, and signs of respiratory disease, such as nasal discharge, ocular discharge, abnormal respiration, and coughing, were moved to the hospital area of the feedlot for closer observation. Upon presentation at the hospital facility, the rectal temperature of the "sick" heifer was taken with an electronic thermometer and its identification entered into the chute-side computer (Fusion, SSG Fusion, Picture Butte, Alberta). Lame cattle were scored at the time of treatment using a previously described 5-point scale (Desrochers et al., 2001) where a score of 0 is normal and a score of 5 is non-ambulatory. Animals, regardless of treatment group, were treated according to the feedlot's standard treatment protocol. Therapeutic drugs were used at label dose with label withdrawals adhered to. Treatment dosages were based on the individual body weight of the sick animal. If the animals were moribund at any time, they were humanely euthanized. Feed from these cattle was prorated back to their home pen. Animals that died during the trial period were necropsied by feedlot veterinarians to determine the cause of death.

Pen conditions were assessed weekly by the project field technician according to a 4-point scale (1=dry 0-5 cm, 2= mud depth 5-19 cm, 3= mud depth 20-40 cm, 4 mud depth > 40 cm). A subset of 10 animals/pen were tag scored every week by the project field technician from the start until the end of the trial using a 4-point scale (Grandin, 2009) within their own pens. The scoring method was as follows: 1. Clean, some mud below knees. 2. Mud on the legs above the knees, sides & belly clean 3. Belly mud caked, sides clean. 4. Belly & sides mud caked.

A.3.6 Statistical Analysis

Crude morbidity was calculated by dividing the total treatments of a pen by the number of animals inducted to that pen. Similarly, crude mortality rate was calculated by dividing the total deaths in a pen by the number of head inducted. The total net body weights at processing and shipment were imported into a spreadsheet program (Microsoft Office Excel 2013) and an average weight was calculated for each pen by dividing by the total number of head inducted into the pen. From the computerized animal health data, cause-specific disease rates were calculated for each pen including: foot rot, digital dermatitis.

Days on feed (DOF), daily dry matter intake, average daily gain (ADG), and feed to gain ratio (F:G) were calculated for each pen. Live weight at slaughter were pencil shrunk 4%, which is a common industry standard. Average DOF per pen was calculated as the total head days divided by the number of head inducted. Average daily gain per pen was calculated as the total live weight at slaughter subtract the total weight inducted divided by the total head days. Daily

DMI per pen was calculated as the total pounds of feed fed (on a dry matter basis) divided by the total head days. Feed to gain per pen was calculated as the total pounds of feed fed (dry matter basis) divided by the total live weight gain.

Data were analyzed using an analytical software program (Stata 11, Stata Corp, College Station, TX). A randomized block design was used to compare outcomes between experimental groups. Mixed linear regression models were used to evaluate continuous outcomes and mixed logistic regression models were used to compare proportional outcomes such as morbidity and mortality risk. Replicate (block) was a random effect in all models.

A.4. Results

Results of cattle performance, animal health and behavior are summarized in Tables (A1, A2, and A3, respectively).Yearling heifers housed in pens with amended floors of roller compacted concrete (RCC) were found to have lower crude morbidity ($P<0.01$) due to reduced lameness; specifically, for foot rot ($P < 0.01$) and digital dermatitis ($P < 0.01$), as compared to Clay pens. The severity of lameness did not appear to differ based upon the mean lameness scores of both treatment groups.

Cattle housed on different flooring consumed similar amounts of feed (dry matter basis). However, animal performance as measured by ADG and F:G ratio tended to be improved for heifers housed on RCC versus Clay pens. Average mud depth score was found to be lower for RCC pens which might explain the tendency noted in animal performance. The difference in mud depth is somewhat surprising as the feedlot scraped and bed both pens equally. The study was conducted over relatively dry years (2016 to 2018), so differences in performance and mud depth would likely be quite different in a wet year. Tag scores were also lower for RCC vs Clay floors. Unfortunately, the animal health staff and research technician could not be blinded to the pen floor treatments which could result in bias. We also recognize the difficulty and limitations of assessing mud depth or tag score to a subset of the pen. Trying to apply a more sophisticated approach to assessing these outcomes was considered, but just wasn't practical.

There were no differences in the average hourly behavior of animals in either pen type. However, sample size (type 2 error) and variability in the expression of these behaviors may explain why no statistical differences at $P < 0.05$ were found. Tags were applied to animals from four other pens, but unfortunately due to tag loss (misapplied) and power failure to the router, too much data was missing from both treatment groups and it was decided not to include these animals in the final analysis. We recognize the limited representation in our sample with four to six animals per pen and only sampling 8 of the 42 study pens.

A.5 Endnotes

[a] Express Yearling, Boehringer-Ingelheim Canada Inc., Burlington, ON
[b] Tasvax® 8, Merck Animal Health, Intervet Canada Corp, Kirkland, QC
[c] Bimectin™ Pour-On, Bimedia-MTC Animal Health Inc., Cambridge, ON
[d] Component TE-100®, Elanco Animal Health, Guelph, ON

TABLE A1: Comparison of animal performance for yearling cattle housed on pen floors amended with roller compacted concrete (RCC) versus compacted clay.

	Clay/Mixed	RCC	SEM	P-value
Pens	21	21		
Head	5,516	5,512		
In Wt (*lbs*)	850	852	1.7	0.22
Out Wt (*lbs*)	1,425	1,445	5.4	<0.01
DOF	179	182	1.2	0.02
Daily DM Intake (*lbs*)	22.6	22.6	0.09	0.51
Avg Daily Gain (*lbs*)	3.17	3.23	0.04	0.10
Feed:Gain	7.14	7.02	0.07	0.10

TABLE A2: Comparison of morbidity, mortality, mud, tag and lameness scores in feedlot yearling heifers housed on pen floors amended with RCC versus compacted clay

	Clay/Mixed	RCC	SEM	P-value
Crude Mortality	0.76%	0.65%	0.17%	0.44
Crude Morbidity	40%	27%	7%	<0.01
Total Lameness Treatments	36%	24%	7%	<0.01
Lameness Incidence	32%	21%	5%	<0.01
Footrot Incidence	22%	15%	4%	<0.01
Digital Dermatitis Incidence	8%	4%	2%	<0.01
Lameness Score (0 to 4)	1.13	1.07	0.05	0.13
Tag Score (1 to 4)	1.25	1.20	0.01	<0.01
Mud Depth Score (1 to 4)	1.18	1.13	0.02	<0.01

TABLE A3: Comparison of time (minutes per hour) spent ruminating, eating and activity level (not active, active, highly active) throughout the feeding period of yearling heifers housed on pen floors amended with RCC versus compacted clay.

	Clay	RCC	SEM	P-Value
Hd	17	16		
Pens	4	4		
Avg Hourly Behaviours: *(min/hr)*				
Not Active	23.6	25.4	1.3	0.15
Ruminating	14.2	13.5	1.3	0.62
Eating	2.2	2.5	0.38	0.61
Active	10.6	9.7	1.3	0.42
High Activity	9.5	9.0	0.83	0.42

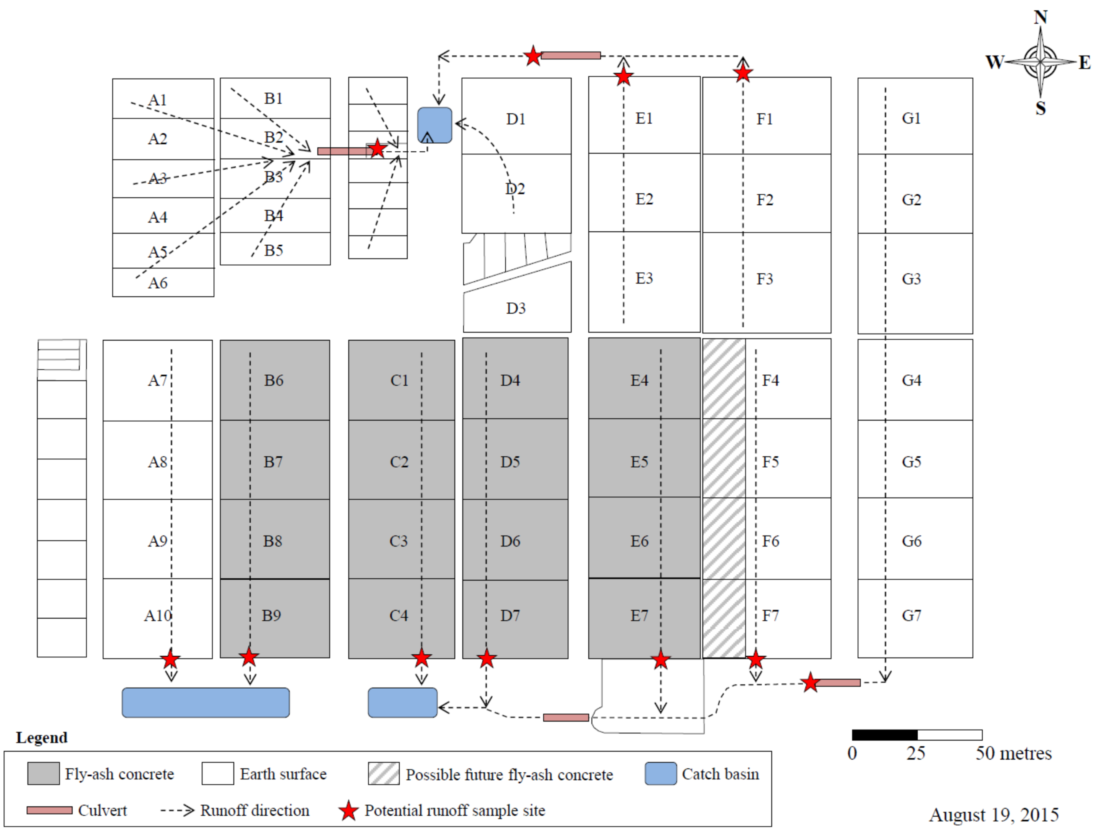

Figure A1. Schematic drawing of the southern Alberta feedlot in which roller compacted concrete pens (Grey) were compared to clay/mixed pens (white/diagonal line).

APPENDIX B: ENGINEERING AND CHEMICAL PROPERTIES OF ROLLER COMPACTED CONCRETE

B.1. Abstract

RCC cores extracted from cattle pens and a silage pad at a commercial feedlot were analyzed for changes in physical properties (compressive strength, density and freeze-thaw weathering loss) and chemical properties (total and leachable metals and non-metals) over a period of three years (2016-2018). Sixteen feedlot pens and the silage pad were retrofitted with RCC in 2015, eleven in 2017 and seven in 2018. The mean compressive strength of the feedlot pens and silage pad retrofitted with RCC in 2015 showed a lot of variability and ranged between 10.6 MPa and 16 MPa, compared to 19.9 MPa and 26.5 MPa, for the pens retrofitted with RCC in 2017 and 2018, respectively. Mean core densities of the RCC installed in 2015 ranged between 2216 $kg.m^{-3}$ and 2328 $kg.m^{-3}$, with low variability within and across floor surfaces. Interestingly, there seemed to be a decline in density with time in the pen and silage pad RCC floor surfaces installed in 2015. Mean densities of the RCC installed in 2017 and 2018 were 2255 $kg.m^{-3}$ and 2276 $kg.m^{-3}$, respectively. Frost weathering freeze-thaw analysis was based on a limited number of samples extracted from some of the pens and silage pad retrofitted with RCC in 2015. Weathering in one of the rows of cattle pens seemed higher than in the other three, and seemingly least in the silage pad RCC. Concentrations of total metals and non-metals, namely boron, calcium, iron, magnesium and manganese were higher in crushed RCC samples from the pens and silage pad retrofitted with RCC in 2015 versus manure samples from the feedlot pens. In contrast, the concentrations of copper, molybdenum, phosphorus, potassium, sodium, sulphur and zinc were higher in the manure. All leachable metal and non-metal concentrations seemed to be well below regulatory levels. Overall, additional study of the RCC properties is recommended to provide clear insight into the useful life (durability) and waste disposal risks associated with the RCC installed at the commercial study site.

B.2. Objectives and Deliverables

The objectives of this aspect of the research study were to:

i) Assess changes in physical and chemical properties of the floor surfaces in sixteen commercial feedlot cattle pens and a silage pad retrofitted with RCC in 2015.

ii) Measure the compressive strengths (physical property) of additional pen floor surfaces at the commercial feedlot, retrofitted with RCC in 2017 and 2018.

B.3. Materials and Methods

B.3.1. RCC Installation

In 2015, approximately 85% of the floor surface area in sixteen pens of the study site were paved with roller compacted concrete (RCC). Fractions of the pen floor surface not covered with RCC (i.e., ≈ 15%) included the concrete apron adjacent to the feed bunk and around the watering trough, and the bedding pack centred in the pen, approximately. Fly ash from a coal-fired power plant located about 215 km from the research site was used as a substitute for 50% of the Portland cement content of the RCC mixture. In addition, aggregates of variable size used in the concrete mixture were obtained from a sand and gravel pit located approximately 15 km from the site.

Rows of pens comprised of four pens each were resurfaced with RCC on May 18, May 25, June 01 and June 05, 2015. The silage pad located on the feedlot was also resurfaced with RCC on June 29. Of the four rows of pens and the silage pad, a different installation technique was used to install the first row of pens re-surfaced on May 18. None of the construction work was completed by a professional engineering firm. In 2017, an additional eleven pens (of smaller surface area) were resurfaced with RCC on October 18, 2017 and seven more (similar-sized pens to the 2015 pens) on July 26, 2018.

B.3.2. RCC Core Collection

RCC cores measuring 10 cm in diameter and of varying lengths ranging between 9 cm and 32 cm were extracted using a concrete coring machine from the respective floor surfaces (six pens and the silage pad in 2016 and 2017, and twelve pens and the silage pad in 2018) and shipped to an engineering firm for subsequent analyses (Wood, 2019). The open boreholes were refilled using a quick setting concrete mix and asphalt. Four cores each were extracted from six of the sixteen cattle pens retrofitted with RCC in 2015. Non-professional installation of RCC in feedlot pens can present a number of challenges, especially in those areas of the pen that are adjacent to the concrete apron and the fences, and in the formation of the runoff swale. Within the feedlot pens, cores were extracted from locations close to the concrete apron (defined as '1-near apron'); alongside a fence (defined as '2-near fence'); in the swale (defined as '3-runoff apron'); and in an open area that allowed for unobstructed compaction of the RCC mixture (defined as '4-good area') (Figure B.1). An additional core was extracted from the silage pad, generally considered as a 'good area'.

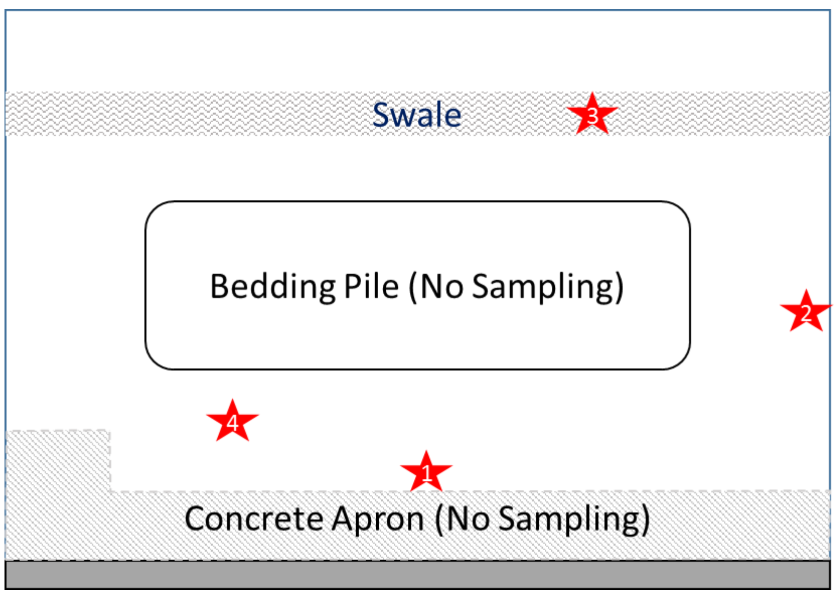

Figure B1. Randomly selected core locations within a generalized feedlot cattle pen floor retrofitted with RCC (not to scale).

In 2016, twenty-four cores were extracted from the six pens retrofitted in 2015 and one core from the silage pad. In 2017, thirty-two cores were extracted from the six pens, with core extraction repeated at all four locations in two pens that year, plus one core from the silage pad. Finally, in 2018, twenty-four cores were extracted from the six pens and one core from the silage pad. In addition, four cores only were extracted from the four locations in three of the four pens retrofitted with RCC in 2017, and three of the four pens retrofitted in 2018. All twelve pens and all core locations (including silage pad) were randomly selected.

B.3.3 RCC Physical Properties

The compressive strength, density and freeze-thaw resistance were measured on the RCC cores collected over time. These properties are indicative of the durability of RCC after continuous exposure to: varying weather conditions; static loading as a result of cattle, hauling trucks and heavy excavation equipment in the pens; dynamic loading as a result of cattle movement, and scraping equipment and hauling trucks (manure, silage, etc.); and chemical exposure to cattle excrement and urine and/or leachate from the silage.

B.3.4 Frost Weathering

In each year, an additional core was extracted from one of the four locations in three of the sixteen pens retrofitted with RCC in 2015. The three pens varied from year to year, with frost weathering pens repeated in some pens over the three year study period. An additional core was extracted from the silage pad for the analysis. While the lengths of the cores were measured and densities calculated, the three additional cores were each weighed and sequentially subjected to thirty cycles of freezing at -9 ^{o}C for 19 h to 21 h, and then thawing at temperatures ranging between 19 ^{o}C and 29 ^{o}C (Wood, 2019). Percentage weight losses of the cores were determined after every ten cycles.

B.3.5 RCC Chemical Properties

Total and leachable [toxicity characteristic leaching procedure (TCLP)] heavy metals were analyzed on the RCC cores collected from six of the sixteen pens retrofitted with RCC In 2015, and one core from the silage pad. Metals analyses were conducted on crushed cores from the compressive strength tests completed on cores extracted in 2016 and 2018. Of the 2016 samples, Wood (2019) analyzed a composite sample from the four cores extracted per pen. In 2018, all twenty four cores extracted from the six pens were analyzed for total and leachable metals.

Wood (2019) reported that total metal analysis of cores extracted in 2016 and 2018 were conducted by different laboratories. Both laboratories seemed to use different reference methods, with different detection limits. In 2016, six composite samples of cores extracted from the six feedlot pens and one sample from the silage pad were analyzed for twenty-seven different soil metals. Of these, ten were metals analyzed for in manure samples from the feedlot in 2017 and 2018. The latter were analyzed by a third independent laboratory with a different reference method. Two other metals, boron and sulphur, analyzed for in the manure were not among the twenty-seven metals analyzed for in the RCC. In 2018, twenty-four samples from cores extracted from the six feedlot pens and a silage pad core were analyzed for thirty-five soil metals, including boron and sulphur.

Similarly, different laboratories, each using different reference methods and associated detection limits, were used to analyze leachable metals, as per TCLP procedures, in the crushed RCC samples in 2016 and 2018. The RCC samples extracted in both years were analyzed for twenty leachable metals.

B.4. Results and Discussion

B.4.1 Compressive Strength

Mean, median, coefficient of variation (CV), maximum and minimum compressive strengths of all ninety-one cores extracted from the commercial feedlot (pens and silage pad) over three years are presented in Table B-1. Furthermore, Figure B2 shows the compressive strengths of all ninety-one cores extracted from the feedlot (pens and silage pad) over three years, in relation to the age of the RCC material (in days since construction) at the time of extraction.

Table B1. Compressive strength (MPa) of commercial feedlot floor surfaces retrofitted with RCC.

Statistic	RCC Floor Surface Source*

	B-row	C-row	D-row	E-row	Small Pens	G-row	All Pens	SP
Mean	15.3	10.6	14.7	16.0	19.9	26.5	14.5	23.4
Median	15.7	9.9	15.3	15.1	19.9	27.5	14.3	23.7
CV (%)	28	55	46	32	5	18	46	25
Maximum	20.3	25.1	28.9	23.4	20.9	30.9	30.9	29.0
Minimum	7.3	2.3	2.5	5.9	19.0	20.0	2.3	17.5
Count	12	28	24	16	4	4	88	3

* B-Row (pens B6-B9), large pens installed June 5, 2015; C-Row (pens C1-C4), large pens installed May 18, 2015; D-Row (pens D4-D7), large pens installed May 25, 2015; E-Row (pens E4-E7),large pens installed June1, 2015; Small Pens refer to pens A1-A6 and B1-B5 installed October 18, 2017; G-row (pens G1-G7), large pens installed July 26, 2018; SP refers to the silage pad installed June 29, 2015; and All Pens refers to composite data for all feedlot pens. Refer to Figure A-1 for lettered-pen locations in the study feedlot.

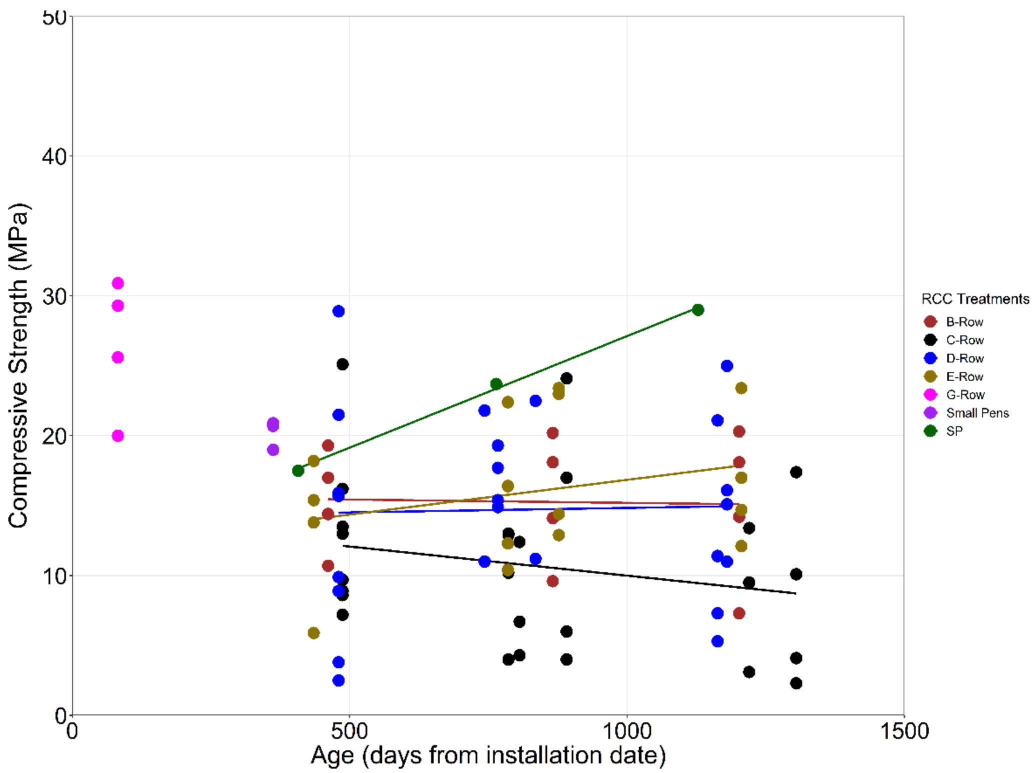

Figure B2. Change in the compressive strength over time of RCC installed in cattle pens and a silage pad on a commercial feedlot operation.

These results indicate that the mean compressive strength of RCC in pens in the C-row was lowest and highly variable. As mentioned in Section B.3.1, a change in installation technique was effected immediately after the C-row of pens were retrofitted with RCC. The variability and low mean compressive strength in the C-row of pens may have been solely due to the initial installation technique, the prevailing weather conditions when the RCC was installed in that row of pens, the composition of the RCC mix at the time of installation, or a combination of some or all factors. Conversely, compared to the mean compressive strength of 'All Pens', the mean compressive strength of the silage pad was higher. However, owing to the limited size of RCC samples extracted from the silage pad for compressive strength analysis, it is uncertain the mean value presented in Table B1 provides an adequate estimate of the population mean compressive strength associated with the silage pad floor surface at the commercial feedlot.

With the compressive strengths of RCC in the small pens and pens in the G-row, there seemed to be less variability, again considering the small sample size. The smaller variability in compressive strength among the cores from each row of pens could have been influenced by the age of the RCC floor surface, and/or the increased level of experience gained with time with respect to the composition of the RCC mix and installation of the product. Given the high variability in compressive strength and limited sample size in some instances, it would seem that the viability and durability (with respect to compressive strength) of the RCC retrofitted in the commercial feedlot pens and the silage pad in 2015, 2017 and 2018, can only be adequately assessed by monitoring continuously, on an annual basis.

B.4.2 Density

Mean, median, coefficient of variation (CV), maximum and minimum densities of ninety-nine cores extracted from the commercial feedlot (pens and silage pad) over three years are presented in Table B2 below. Figure B3 shows the extracted core densities relative to age of the RCC floor surface.

Similar to compressive strength, the mean density of cores extracted from the C-row was lowest among all feedlot pens, while the mean density of the silage pad was the highest compared to the mean density of 'All Pens', again noting the limited size of the RCC samples from the silage pad. In general, the variability in densities of RCC samples among all pen rows and the silage pad were low compared to the variability in compressive strength measurements. This seems to suggest that the composition of the RCC mix was relatively uniform across all floor surfaces at the feedlot. Interestingly, a decline in RCC densities with time among all floor surfaces, including the silage pad, was observed (Figure B3). Pens in the E-row showed the highest rate of decline, and pens in the C-row showed the lowest rate of decline.

Table B2. Density ($kg \cdot m^{-3}$) of commercial feedlot floor surfaces retrofitted with RCC.

Statistic	**RCC Floor Surface Source***							
	B-row	**C-row**	**D-row**	**E-row**	**Small Pens**	**G-row**	**All Pens**	**SP**
Mean	2287	2216	2262	2284	2255	2276	2254	2328
Median	2278	2227	2270	2278	2269	2289	2256	2318
CV (%)	1.4	2.1	2.0	1.7	2.0	1.3	2.2	0.7
Maximum	2350	2311	2350	2345	2289	2296	2350	2347
Minimum	2254	2086	2164	2217	2193	2231	2086	2312
Count	12	31	26	17	4	4	94	5

**Rows B-Row (pens B6-B9), large pens installed June 5, 2015; - C-Row (pens C1-C4), large pens installed May 18, 2015; D-Row (pens D4-D7), large pens installed May 25, 2015; E-Row (pens E4-E7), were large pens installed on separate events inJune1, 2015,; small refer to pens A1-A6 and B1-B5 installed in October 18, 2017 ,; G-row (pens G1-G7), was installed in large pens installed in July 26, 2018,; SP refers to the silage pad installed June 29, 2015,; and All Pens refers to composite data for all feedlot pens. Refer to Figure A-1 for lettered-pen locations in the study feedlot.

B.4.3 Freeze-Thaw Resistance

Mean, maximum and minimum percentage weight losses after sequential exposure to 10, 20 and 30 freezing and thawing cycles of twelve cores extracted from the commercial feedlot (pens and silage pad) over three years are presented in Table B3. Furthermore, Figure B4, shows the distribution of the percentage weight loss relative to the age of the RCC floor surface.

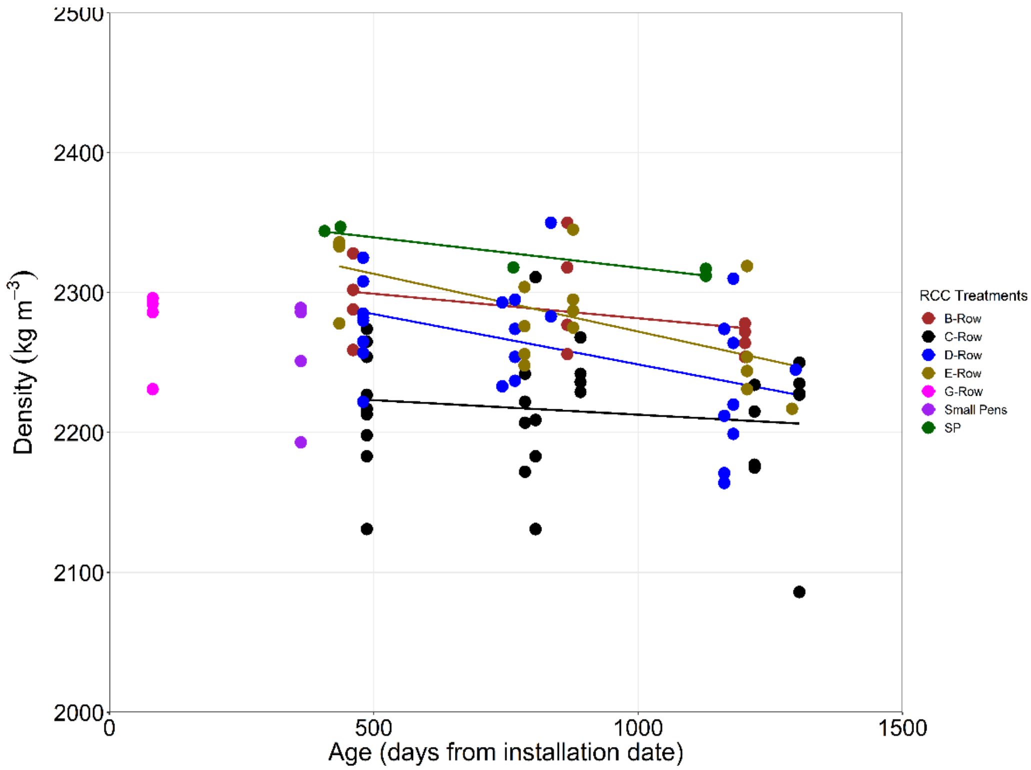

Figure B3. Changes in the density over time of RCC installed in cattle pens and a silage pad on a commercial feedlot operation.

Table B3. Frost weathering (% weight loss) of commercial feedlot floor surfaces retrofitted with RCC.

Statistic	**Weathering Loss after 10 Freeze-Thaw Cycles**				
	C-row	**D-row**	**E-row**	**All Pens**	**SP**
Mean	0.22	0.20	0.47	0.27	0.02
Maximum	0.72	0.46	0.93	0.93	0.04
Minimum	0.02	0.03	0.01	0.01	0.00
Count	4	3	2	9	3
Statistic	**Weathering Loss after 20 Freeze-Thaw Cycles**				
	C-row	**D-row**	**E-row**	**All Pens**	**SP**
Mean	0.38	0.30	1.61	0.63	0.03
Maximum	1.03	0.54	2.84	2.84	0.05
Minimum	0.04	0.04	0.38	0.04	0.01
Count	4	3	2	9	3
Statistic	**Weathering Loss after 30 Freeze-Thaw Cycles**				

	C-row	D-row	E-row	All Pens	SP
Mean	0.79	0.42	1.99	0.93	0.03
Maximum	1.52	0.75	3.60	3.60	0.05
Minimum	0.04	0.04	0.38	0.04	0.02
Count	4	3	2	9	3

Although based on a rather limited number of samples, mass loss in the RCC in pens in the E-row was highest, becoming more prominent with increasing number of freeze thaw cycles (Figure B4). If this is indeed a depiction of what occurs, then in years when the ambient air temperature fluctuates frequently, an increase in RCC disintegration due to frost weathering can be expected to occur in the feedlot pen floor surfaces retrofitted with RCC.

In contrast, the percentage weathering loss in the silage pad RCC was the lowest and seemed to remain relatively steady with time. This raises the notion that the presence of cattle in pens with the RCC floor surface may compromise the ability of the RCC floor surface to withstand freeze-thaw cycling, possibly due to a combination of physical (static and dynamic loads) and chemical (feces and urine) degradation. However, a more focused examination of this hypothesis is necessary.

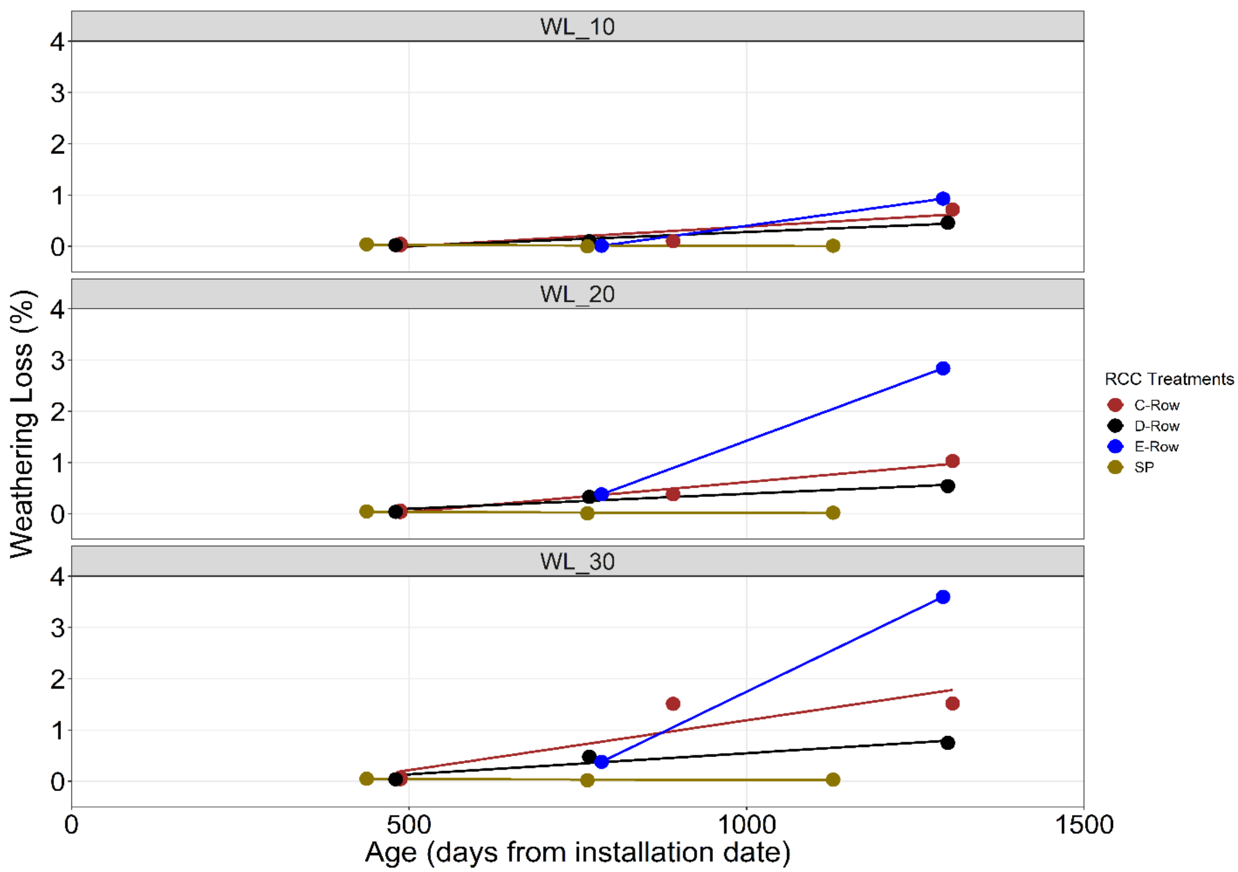

Figure B4. Percentage weight loss after 10, 20, 30 freeze-thaw cycles of RCC cores extracted over time in cattle pens and a silage pad on a commercial feedlot operation.

B.4.4 Total and Leachable Metals

Mean concentrations and standard errors of the mean (SEM) of total metal and non-metal elements in the respective RCC floor surfaces, manure samples from feedlot pens with different types of floor surfaces, and a clay sample from a stockpile meant for repairing damaged clay floor surfaces, are presented in Table B5.

The results of the chemical analyses (in 2016 and 2018), indicates that the RCC material may have elevated concentrations of boron, calcium, iron, magnesium, and manganese, in comparison to manure samples from the pens. Conversely, the RCC materials seems to have lower concentrations of copper, molybdenum, phosphorus, potassium, sodium, sulphur, and zinc, in comparison to manure samples from the pens. All total metals concentrations, with the exception of zinc, which is enriched in manure, are below the Alberta Tier 1 Guidelines for Soil and Groundwater Remediation for Agricultural Soil. Although feedlot settings do not necessarily meet the conditions in which the risk-based guidelines for agricultural soils were developed, these results suggest that the RCC material does not present an inherent risk to feedlot cattle or to agricultural soils where manure collected from feedlots are disposed. As mentioned in Section B.3.5, two different laboratories conducted the analysis for leachable metals and non-metals in crushed RCC samples in 2016 and 2018, both using different detection limits. The detection limits used by the analytical laboratory in 2018 were higher, which seems to have allowed for all measurements of leachable metal and non-metal concentrations to read below the detection limit of the analytical procedures used for the analysis. Table B5 shows the mean concentrations of leachable metals and non-metals in the RCC from the pens and the silage pad following the analyses in both years, as well as the detection limits relative to the respective laboratories. These results suggests there is no risk associated with leachable metals and non-metals from the RCC used on the commercial feedlot in comparison to provincial regulatory levels (AG 1996).

Table B4. Mean concentrations of metal and non-metal solid elements present in RCC, manure and clay soil from a commercial cattle feedlot.

Elements	Sample Source						
		RCC Floor Surface		Manure		Clay	
	AB Tier 1: Agricultural Soil	Cattle Pen	Silage Pad	RCC Pen	RCC & Clay Pen	Clay Pen	Stockpile
Aluminum ($g.kg^{-1}$)		10.9±0.37 (n = 30)	9.5±1.16 (n = 2)				
Antimony ($mg.kg^{-1}$)	20	0.57±0.03 (n = 24)	0.51 (n = 1)				
Arsenic ($mg.kg^{-1}$)	17	7.6±0.31 (n = 30)	8.9±0.37 (n = 2)				
Barium ($g.kg^{-1}$)	0.75	0.53±0.03 (n = 30)	0.35±0.04 (n = 2)				
Beryllium ($mg.kg^{-1}$)	10,000	0.60±0.03 (n = 30)	0.45±0.05 (n = 2)				
Bismuth ($mg.kg^{-1}$)		below detection<0.20	<0.20				
Boron ($g.kg^{-1}$)	3.3 mg/L saturated paste	0.15±0.01 (n = 24)	0.08 (n = 1)	0.02±0.00 (n = 61)	0.01±0.00 (n = 11)	0.02±0.00 (n = 42)	0.02 (n = 1)
Cadmium ($mg.kg^{-1}$)	3.8	0.16±0.01 (n = 26)	0.17±0.04 (n = 2)				
Calcium ($g.kg^{-1}$)		68.5±2.56 (n = 30)	74.2±14.55 (n = 2)	18.6±0.37 (n = 61)	18.3±0.65 (n = 11)	18.1±0.40 (n = 42)	24.1 (n = 1)
Chromium ($mg.kg^{-1}$)	64	18.2±0.77 (n = 30)	11.5±0.20 (n = 2)				
Cobalt ($mg.kg^{-1}$)	20	4.9±0.28 (n = 30)	3.7±0.01 (n = 2)				

Elements	Sample Source						
		RCC Floor Surface		Manure		Clay	
	AB Tier 1: Agricultural Soil	**Cattle Pen**	**Silage Pad**	**RCC Pen**	**RCC & Clay Pen**	**Clay Pen**	**Stockpile**
Copper ($mg.kg^{-1}$)	63	11.1±0.62 (n = 30)	14.3±4.15 (n = 2)	50.2±1.39 (n = 61)	42.6±1.73 (n = 11)	41.2±1.00 (n = 42)	6.2 (n = 1)
Iron ($g.kg^{-1}$)		17.5±0.63 (n = 30)	17.0±0.35 (n = 2)	2.5±0.22 (n = 61)	4.6±0.60 (n = 11)	7.5±0.44 (n = 42)	18.4 (n = 1)
Lead ($mg.kg^{-1}$)	70	6.0±0.24 (n = 30)	5.2±0.96 (n = 2)				
Lithium ($mg.kg^{-1}$)		8.0±0.26 (n = 24)	8.0 (n = 1)				
Magnesium ($g.kg^{-1}$)		11.3±0.61 (n = 30)	9.4±0.26 (n = 2)	6.9±0.19 (n = 61)	7.2±0.30 (n = 11)	7.2±0.21 (n = 42)	10.1 (n = 1)
Manganese ($g.kg^{-1}$)		0.55±0.03 (n = 30)	0.49±0.15 (n = 2)	0.19±0.01 (n = 61)	0.20±0.01 (n = 11)	0.22±0.01 (n = 42)	0.31 (n = 1)
Mercury ($mg.kg^{-1}$)	6.6	0.04±0.00 (n = 24)	0.03 (n = 1)				
Molybdenum ($mg.kg^{-1}$)	4	1.5±0.07 (n = 30)	1.2±0.15 (n = 2)	7.4±0.56 (n = 61)	15.9±3.31 (n = 11)	20.3±2.83 (n = 42)	5.9 (n = 1)
Nickel ($mg.kg^{-1}$)	45	11.3±0.26 (n = 30)	9.8±0.48 (n = 2)				
Phosphorus ($g.kg^{-1}$)		0.36±0.01 (n = 30)	0.30±0.00 (n = 2)	10.2±0.27 (n = 61)	10.1±0.39 (n = 11)	7.7±0.19 (n = 42)	0.5 (n = 1)
Potassium ($g.kg^{-1}$)		1.6±0.07 (n = 30)	1.6±0.30 (n = 2)	28.2±0.69 (n = 61)	23.2±1.15 (n = 11)	19.2±0.49 (n = 42)	3.2 (n = 1)
Selenium ($mg.kg^{-1}$)	1	0.57±0.04 (n = 24)	0.23 (n = 1)				
Silver ($mg.kg^{-1}$)	20	0.11±0.00 (n = 4)	below detection				

Elements	Sample Source						
		RCC Floor Surface		Manure		Clay	
	AB Tier 1: Agricultural Soil	Cattle Pen	Silage Pad	RCC Pen	RCC & Clay Pen	Clay Pen	Stockpile
Sodium (g.kg^{-1})		0.87±0.06 (n = 30)	0.67±0.22 (n = 2)	1.12±0.05 (n = 61)	1.12±0.07 (n = 11)	1.01±0.03 (n = 42)	0.50 (n = 1)
Strontium (g.kg^{-1})		0.21±0.01 (n = 24)	0.14 (n = 1)				
Sulphur (g.kg^{-1})		1.5±0.05 (n = 21)	1.1 (n = 1)	5.7±0.17 (n = 61)	5.6±0.12 (n = 11)	4.5±0.11 (n = 42)	2.4 (n = 1)
Thallium (mg.kg^{-1})	1	0.16±0.01 (n = 24)	0.19 (n = 1)				
Tin (mg.kg^{-1})	5	below detection	below detection				
Titanium (g.kg^{-1})		0.46±0.01 (n = 24)	0.34 (n = 1)				
Tungsten (mg.kg^{-1})		0.59±0.03 (n = 10)	<0.50				
Uranium (mg.kg^{-1})	23	1.5±0.06 (n = 24)	1.9 (n = 1)				
Vanadium (mg.kg^{-1})	130	36.1±2.21 (n = 30)	20.3±0.65 (n = 2)				
Zinc (g.kg^{-1})	0.25	0.03±0.00 (n = 30)	0.04±0.00 (n = 2)	0.28±0.01 (n = 61)	0.25±0.01 (n = 11)	0.21±0.00 (n = 42)	0.05 (n = 1)
Zirconium (mg.kg^{-1})		19.9±0.66 (n = 24)	14.8 (n = 1)				

Table B5. Mean concentrations (mg.L^{-1}) of metal and non-metal leachable elements present in RCC in comparison to regulatory levels (AG 1996).

Elements	Source						
	RCC Floor Surface (2016)			RCC Floor Surface (2018)			Regulatory Level
	Pen Floor	Silage Pad	Detection Limit	Pen Floor	Silage Pad	Detection Limit	
Antimony	0.004	below detection	0.0020	below detection	below detection	5.000	500
Arsenic	0.006	below detection	0.0050	below detection	below detection	0.200	5.0
Barium	0.721	0.97	0.0300	below detection	below detection	5.000	100
Beryllium	below detection	below detection	0.0010	below detection	below detection	0.500	5.0
Boron	3.878	0.97	0.1000	below detection	below detection	5.000	500
Cadmium	below detection	below detection	0.0001	below detection	below detection	0.050	1.0
Chromium	0.061	0.02	0.0010	below detection	below detection	0.500	5.0
Cobalt	0.002	0.002	0.0010	below detection	below detection	5.000	100
Copper	0.006	0.013	0.0020	below detection	below detection	5.000	100
Iron	below detection	below detection	0.0100	below detection	below detection	5.000	1000
Lead	below detection	below detection	0.0010	below detection	below detection	0.500	5.0
Mercury	below detection	below detection	0.0100	below detection	below detection	0.010	0.2
Nickel	0.003	below detection	0.0020	below detection	below detection	0.500	5.0
Selenium	below detection	below detection	0.0050	below detection	below detection	0.200	1.0
Silver	below detection	below detection	0.0010	below detection	below detection	0.500	5.0
Thallium	below detection	below detection	0.0020	below detection	below detection	0.500	5.0
Uranium	below detection	below detection	0.0100	below detection	below detection	1.000	2.0
Vanadium	0.032	0.03	0.0010	below detection	below detection	5.000	100
Zinc	0.004	below detection	0.0020	below detection	below detection	5.000	500
Zirconium	below detection	below detection	1.0000	below detection	below detection	5.000	500

APPENDIX C: RUNOFF AND SEEPAGE WATER QUALITY

C.1 Abstract

The influence of roller compact concrete (RCC) on runoff volumes, and concentrations and event-based export of water quality parameters in runoff were assessed over a three year (2016 – 2018) period in comparison to the standard clay-based pen floor substrate at an operational feedlot. Sub-pen soil quality was also assessed annually at three replicate pens each of RCC- and clay-based pen floor substrates. Runoff coefficients, or the proportion of precipitation leaving as runoff, was higher on average in alleys draining RCC-lined pens (18% runoff) than in alleys draining clay-lined pens (7% runoff). Higher runoff in RCC pens resulted in significantly greater export of solids and nutrients. Concentrations of heavy metals tended to be higher in alleys draining clay-lined pens, likely due to the entrainment of metal-enriched clays, resulting in relatively equivalent event-based export. However, metals enriched in manure, such as copper and zinc, demonstrated higher export during runoff events. Differences in soil quality were generally attributed to soil depth rather than pen floor substrates. However, significant differences between clay and RCC pens were observed with total available nitrogen, ammonia-nitrogen, chloride and electrical conductivity, with these parameters being higher in clay substrates of clay-lined pens. This result suggests that RCC may be acting as a cap that guards against the percolation of manure constituents into soil and, eventually, groundwater. However, follow-up studies specifically designed to monitoring percolate into soils are recommended to confirm this observation. Taken together, these results suggest that feedlot operators adopting RCC as a pen floor substrate would have to engage in more frequent pumping and excavation of catch basin water and sediment, respectively, and would have to ensure adequate nutrient management plans are in place to accommodate the greater nutrient loading onto fields receiving catch basin contents.

C.2 Objectives

The goal of this component of the study is to assess whether RCC, as durable alternative to clay substrates, will result in measurable changes to soil quality and runoff quantity and quality either through changes in the transport of manure constituents or by introduction of heavy metals by RCC material. The objectives of this component of the study are to evaluate differences in:

i. Runoff volume between RCC and clay pens during rainfall events;
ii. Concentrations (e.g., mg/L) of water quality parameters (e.g., nutrients, solids) as well as mass export per unit area (e.g., kg/ha) that integrates potential changes in runoff volumes; and,
iii. Concentrations of soil quality parameters at varying depths over time to examine whether RCC material is altering seepage into soil profiles.

C.3 Materials and Methods

C.3.1 Meteorological Monitoring

A meteorological station was installed to measure specific meteorological variables occurring at the site. The station included sensors for measuring temperature and relative humidity (Model HMP60, Vaisala Corporation), wind speed and direction (Model 05103-10, R.M. Young Company), and precipitation (Model T-200B, Geonor Inc.), interfaced to a common datalogger (Model CR-1000, Campbell Scientific) instrumented with a cellular model (MicroHard Systems Inc.) for remote access. The station was instrumented on a portable trailer and positioned within a fenced enclosure in a corral to the southwest of the feedlot. The temperature and relative humidity and precipitation sensors were positioned 1.5 m from ground surface and the wind speed and direction sensors was positioned 2.0 m from ground surface. Wind speed and direction was measured once per second and logged in ten minute intervals; wind speed was reported as an average and wind direction was reported as a wind vector mean. Air temperature, relative humidity, and precipitation were measured and logged in hourly intervals. Alerts were sent when precipitation exceeded 15 mm within a 24 hour period, which is the minimum amount where runoff initiation was observed. Meteorological data collected from the study site was compared against long-term (1961 – 2016) normals collected from the Iron Springs station, part of the Alberta Climate Information Service (ACIS), located 6.2 km southwest of the study site.

C.3.2 Runoff Monitoring

Flumes were constructed at the terminal end of each of eight alleys. Four alleys contained pens completed with RCC flooring, and four alleys contained pens with clay flooring. At the onset of the study, 18” (0.457 m) diameter circular flumes were installed at each alley. After the first year, the circular flumes were replaced with 2’ (0.61 m) H-flumes in order to mitigate build-up of solids at the measurement interface and to facilitate cleaning and maintenance of the flumes. The flumes were instrumented with pressure transducers (Levelogger Edge, Solinst Ltd.) to measure continuous water level, and automated water samplers (6712 Portable Sampler, Teledyne ISCO) to collect event-based water samples. Grab samples were collected during spring thaw owing to ice build-up in the transducer port, which affected water level measurements. Collected water samples were analyzed for solids (total, volatile, dissolved), nutrients (nitrogen and phosphorus parameters), routine water chemistry, and heavy metals (Alberta Tier 1 Soil and Groundwater Remediation Guidelines).

In total, 10 runoff events were sampled for laboratory analysis and 12 events generated measurable runoff for analyzing runoff quantity. Seven events had simultaneous flow volume and water quality sample collections. Event-based export coefficients (mass per unit area) were calculated as the product of water quality parameter concentrations (mg/L) and runoff volume per unit area of the monitored alley. The remaining three runoff events collected for laboratory analysis were spring runoff events. In these events, the runoff was more of a high-solids, slurry-type consistency. Consequently, the laboratory analyzed the samples through processing as a solid-waste material, which required an extraction step prior to analysis. These analyses were reported in mass per unit mass (e.g., mg/kg) and converted to mass per unit volume (e.g., mg/L) to compare between sample events by multiplying the sample results be the reported sample density (g/L).

C.3.3 Soil Profile Monitoring

Soil sampling proceeded through a repeated measures, randomized block design. Soil profile samples were collected in three randomly-selected pens of each pen floor type (clay vs. RCC). Sample events occurred in September of each year of study (2016 – 2018) to test for temporal change in soil parameters. In each pen, soil samples were collected from four depth increments in each of five sample locations. The depth increments included the clay liner overlying the native soil material, and three depth increments (0 – 20 cm, 20 – 40 cm and 40 – 60 cm) into the native soil material; the increments were labelled as Clay, Native Soil (NS) 1, NS2, and NS3, respectively. A clay liner was present underlying the RCC pen substrates, since this material was applied to pens with degraded clay liners as a substitute material. Soil material was composited with the corresponding depth zones, and a subsample was analyzed for soil chemical parameters.

C.3.4 Statistical Analysis

Generalized linear mixed models (*lme4* package 1.1-20, in *R* v.3.5.1) were applied to determine the significance of feedlot pen floor type (clay vs. RCC) on runoff volumes, and water quality parameter concentrations and export coefficients. In the model, floor type and event number were identified as fixed effects and included as crossed factors. Random effects included the alley, to account for repeated measures, and event number, to account for differences in events on individual alleys. All parameters were modelled using Gaussian distributions. Logarithmic links were applied where the dependent variable demonstrated lognormal distributions; otherwise, identity links were applied. Wald tests, using the *anova.lme* function of the *nlme* package, were performed to test for significance of the fixed effects.

The significance of the pen floor material (clay vs. RCC) was assessed using generalized linear mixed modelling (*lme4* package in *R*). Fixed factors included pen floor type (clay vs. RCC), soil depth increment, and year of sampling. Random factors included the pen number, to account for repeated measures, and the year of sampling, to account for differences in time within each pen. Logarithmic links were applied where the dependent variable demonstrated strong logarithmic distributions; otherwise, identity links were applied. Pairwise comparisons were conducted using Tukey adjustments in the *emmeans* (v. 1.3.3; package in R. Comparisons were only performed on soil horizon within pen floors, and soil horizon between pen floors in order to focus on the practical question of whether feedlot pen floor substrates were leading to significant changes in soil quality. The effect of year was not examined in pairwise comparisons owing to the low instance or contradictory results of the effect of year that was likely an artefact of the high variability observed in the soil data.

C.4 Results and Discussion

C.4.1 Meteorological Conditions

Meteorological data collected on the study site was compared long-term normal estimates from the Iron Springs ACIS station (Figures C1 and C2). In general, the monthly average temperatures conformed with the long-term normal during the study period, although some anomalies were encountered. Higher-than-normal temperatures were observed in October 2016; July, August and November 2017; and May 2018. Lower-than-normal temperatures were observed in July, August and September 2016, and February and March of 2018. Monthly accumulated precipitation exceed long-term normals July through October 2016, February 2017 and February 2018. Lower-than-normal monthly precipitation accumulations occurred in May – September 2017, December 2017 – January 2018, and May – June 2018. All storm events that generated measurable runoff volumes during this study were relatively common, with the highest return interval encountered being a 1:5 year storm event; all other events were less than or equal to 1:2 year events (Table C1).

C.4.2 Runoff Quantity and Quality

On a per-storm basis, runoff emitting from RCC-based pens was greater than that emitting clay-based pens, as evidenced by the significantly ($p<0.01$) greater runoff coefficients of the RCC pens over the clay pens. The runoff coefficients denote the proportion of precipitation that forms runoff. In the RCC pens, the runoff percentage has a mean of 18%, a median of 17%, and ranged between 1% and 58% over the course of the study. In contrast, the clay pens had a runoff percentage with a mean of 7%, median of 5%, and ranged between <1% and 36% over the course of the study (Figure C3). The observed variability in the runoff coefficients were likely due to factors such as precipitation intensity, volume, duration and antecedent precipitation and soil moisture. The runoff coefficients appeared relatively consistent among the RCC alleys; however, the runoff coefficients seemed to vary among the clay pens draining to the north of the feedlot versus the south, perhaps due to either lower areal coverage or slope (Figure C4). It is also noted that alley F-south consisted of approximately 50% RCC material along the back of the pens and encompassing the drainage swale; the inclusion of RCC material in this pen did not appear to influence the runoff coefficients as it was similar to the comparator clay alley, A-south. Accordingly, and resulting from the relatively low amount of data collected over the course of the study, the 'mixed' treatment containing partial RCC coverage was included as a clay alley in all statistical analyses.

On a concentration basis, the quality of the runoff leaving the RCC alleys was comparable to that of clay alleys for solids and nutrient parameters (Table C2). This observation is likely due to comparable levels of manure being entrained in the runoff. However, concentrations of heavy metals were higher in the runoff sourced from clay alleys in comparison to RCC alleys, likely due to the entrainment of clay (and associated metals) in the runoff. On an export basis, significantly higher export of solids and nutrients were observed in RCC alleys (Table C3). Export is a function of runoff volume, so the significantly greater export of solids and nutrients is a result of the higher runoff volumes in the RCC alleys. For the heavy metal parameters, export was relatively comparable between the clay and RCC alleys, because of the significantly higher concentrations of metals and lower runoff volumes emitting from clay alleys. However, metals that tend to be enriched in manure, such as copper and zinc, demonstrated significantly higher export in RCC alleys than clay alleys owing to the higher runoff volumes.

C.4.3 Soil Profile Monitoring

In this study, the comparison between RCC and clay pen floors on soil quality was limited by the substantial differences in soil quality parameters between soil horizons, the high variability of soil constituents, and the limited duration of the study period. Primarily, significant differences in soil quality parameters were driven by sample depth. The clay material overlying the native soil horizons was generally higher in concentrations except for the in the case of total organic carbon, total nitrogen, and available phosphorus, which were enriched in the native topsoil (NS1; 0 – 20 cm) material (Table C4). However, significant differences between RCC and clay pens were noted for concentrations of total available nitrogen, ammonia-nitrogen, chloride, and electrical conductivity in the upper clay material (Table C4). These results demonstrate that RCC material may be an effective cap that guards against the percolation of manure constituents into the soil profile. The sampling year was observed to have significant interactive effects with soil depth; however, there was no consistency in the temporal trend as some parameters tended to increase and others decreased for different horizons over time. Consequently, these results were not reported in the pairwise comparisons. The lack of significant differences that can be attributed to pen floor type is likely a result of a combination of the heterogeneity of soil, the relatively low sample numbers collected to capture soil heterogeneity, and the short-term nature of the study. Additional studies would be required to better test the hypothesis that RCC material can be protective of groundwater impacts by reducing percolation of manure constituents.

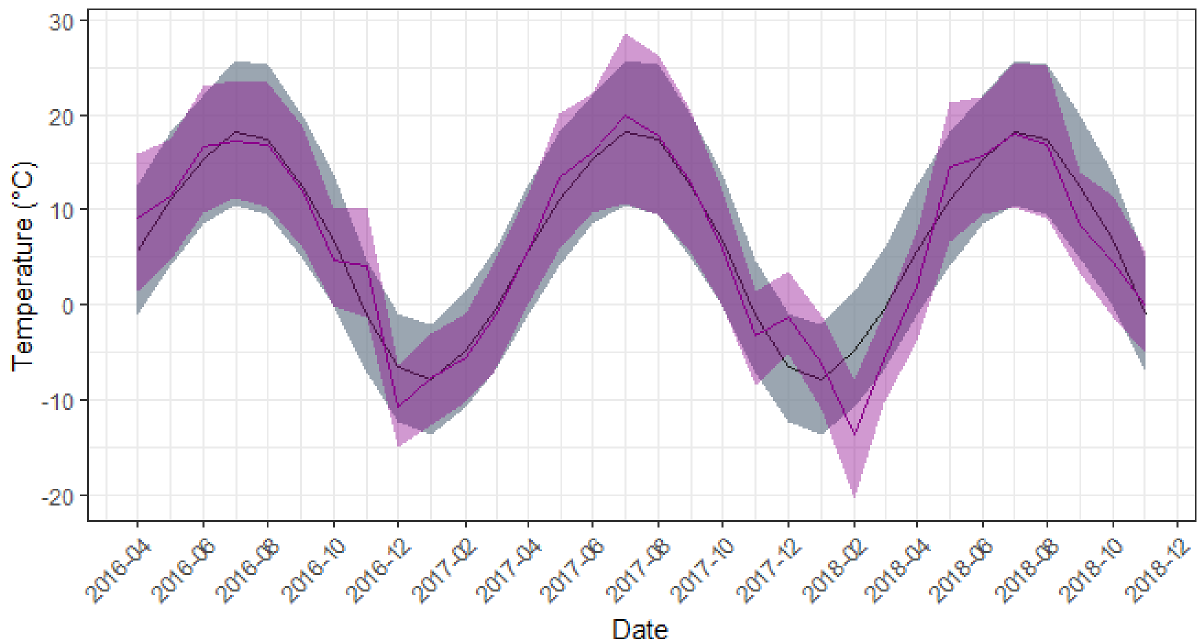

Figure C1. Monthly average, minimum and maximum (magenta) daily temperatures for the study site contrasted against the long-term normal monthly average, minimum and maximum (grey) daily temperatures measured at the Iron Springs ACIS station located 6.2 km southwest from the site.

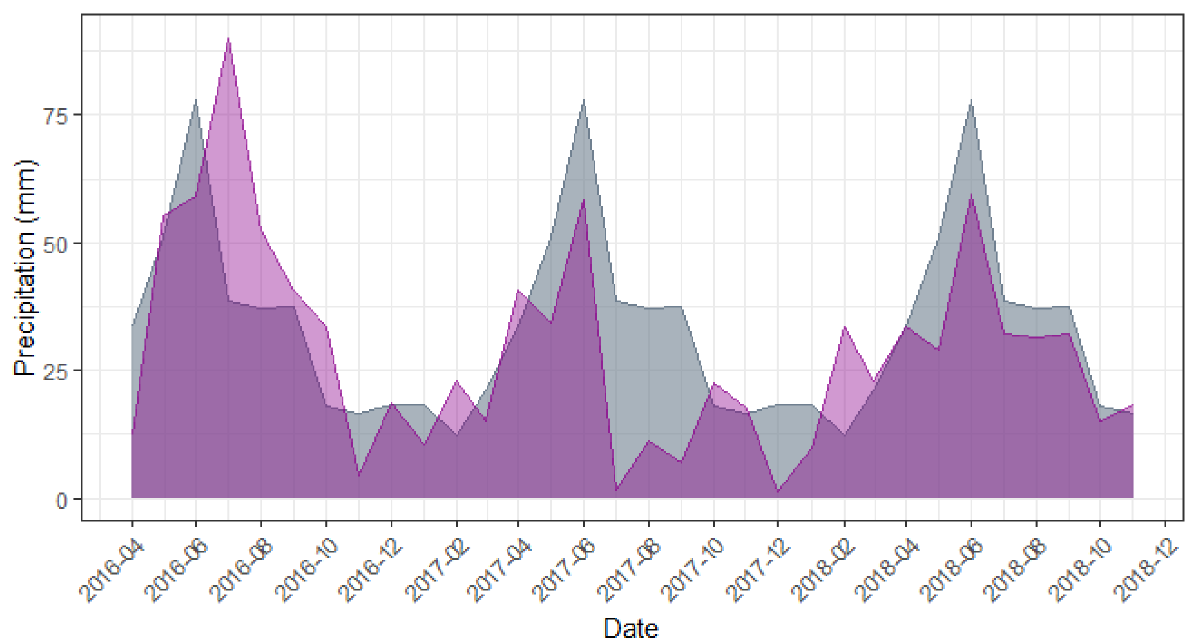

Figure C2. Monthly cumulative precipitation for the study site (magenta) contrasted against the long-term normal (grey) monthly cumulative precipitation measured at the Iron Springs ACIS station located 6.2 km southwest from the site.

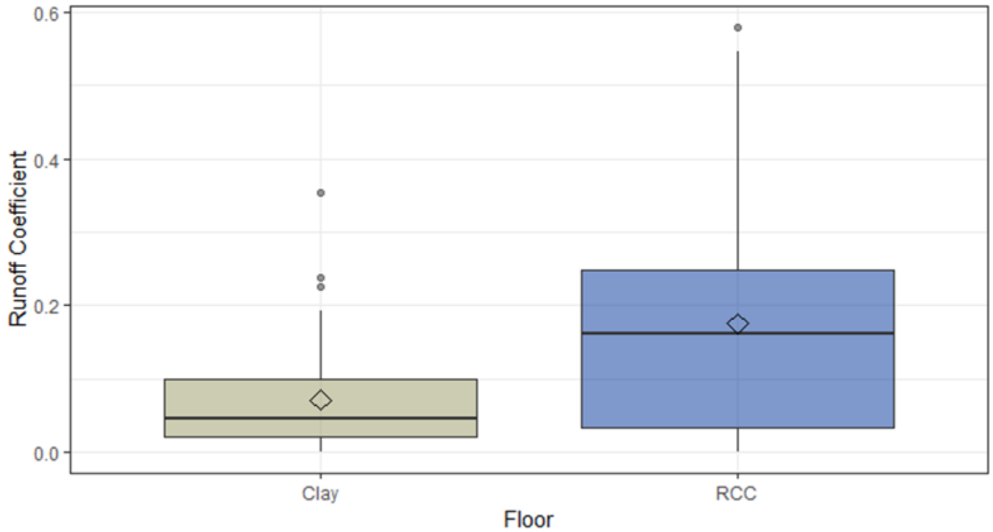

Figure C3. Distribution of runoff coefficients (ratio of runoff to precipitation volumes) measured in clay and RCC alleys. Boxes indicate the interquartile (25^{th} – 75^{th} percentile) range; horizontal line represents the median (50^{th} percentile); whiskers represent the 5^{th} and 95^{th} percentile; and points represent outlier (>95^{th} percentile) values. Mean values are represented by diamond symbols.

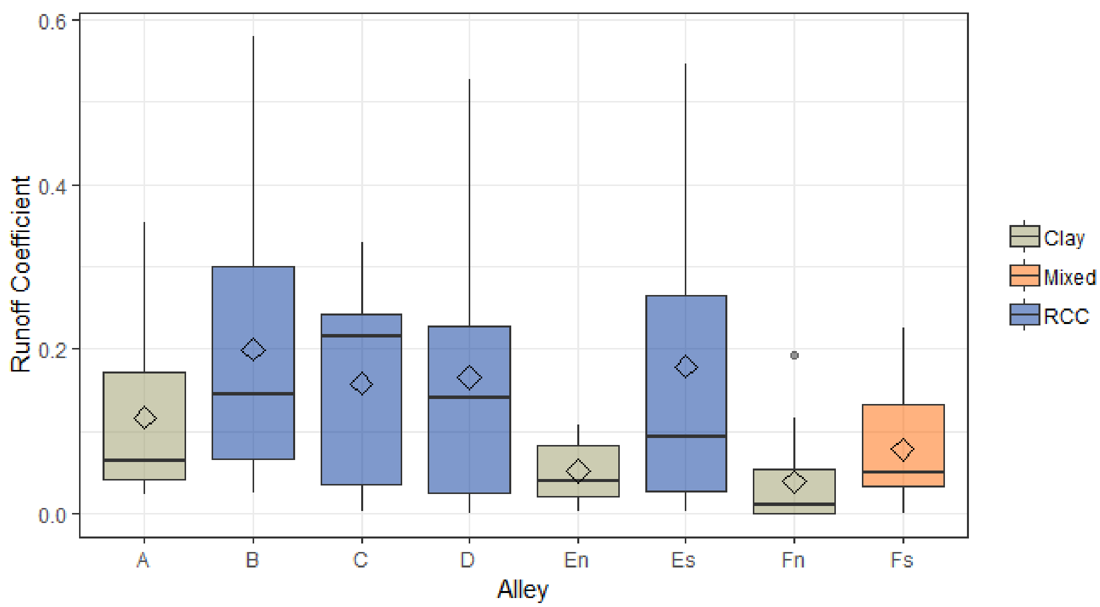

Figure C4. Boxplots of the runoff coefficient distributions measured in each alley, coloured according to the pen floor type. Boxes indicate the interquartile (25^{th} – 75^{th} percentile) range; horizontal line represents the median (50^{th} percentile); whiskers represent the 5^{th} and 95^{th} percentile; and points represent outlier (>95^{th} percentile) values. Mean values are represented by diamond symbols.

Table C1. Properties of the precipitation events resulting in measurable runoff in the study flumes and the associated runoff depth and runoff coefficients measured at the outlet of clay and RCC alleys.

Event No.	Precipitation	Duration	Average Intensity	Maximum Intensity	Estimated Return Interval	Clay Alleys				RCC Alleys			
						Runoff Depth (mm)		Runoff Coefficient		Runoff Depth (mm)		Runoff Coefficient	
	mm	h	mm/h	mm/h	years	Mean	sd	Mean	sd	Mean	sd	Mean	sd
1	26.3	60	0.4	5.5	<2	0.85	0.19	0.028	0.010	1.59	0.31	0.058	0.011
2	28.5	9	3.2	18.2	<2	3.10	2.33	0.101	0.085	13.31	3.55	0.466	0.125
3	16.0	5	3.2	8.8	<2	1.05	1.21	0.063	0.077	2.98	0.91	0.187	0.057
4	22.3	18	1.2	6.1	<2	0.28	0.32	0.011	0.012	0.28	0.27	0.013	0.012
5	17.6	17	1.0	3.5	<2	0.51	0.41	0.029	0.023	0.57	0.53	0.032	0.030
6	12.5	2	6.3	10.7	<2	0.28	0.30	0.022	0.024	1.97	2.52	0.209	0.201
7	21.7	5	4.3	7.9	2	2.74	1.10	0.126	0.051	6.35	1.67	0.293	0.077
8	14.1	22	0.6	3.2	<2	0.30	0.37	0.021	0.027	0.26	0.20	0.019	0.015
9	14.1	43	0.2	0.4	<2	1.59	2.28	0.109	0.163	2.13	1.27	0.151	0.090
10	24.0	24	1.0	2.3	<2	2.72	0.96	0.113	0.040	5.77	0.85	0.241	0.035
11	24.3	32	0.8	5.2	<2	2.21	2.56	0.091	0.105	2.11	0.82	0.087	0.034
12	19.6	12	1.6	4.9	5	2.73	0.99	0.139	0.051	7.02	2.79	0.358	0.142

Table C2. Summary statistics and significance of fixed effects for concentrations of water quality parameters measured in runoff emitting from feedlot alleys containing clay or RCC floor substrates.

Parameter	Unit	Clay Floors						RCC Floors						Significance of Fixed Effects*		
		N	Mean	sd	Median	25%	75%	N	Mean	sd	Median	25%	75%	F	E	F × E
Total Suspended Solids	mg/L	19	11675	12860	7000	3340	12400	26	10311	11734	5840	3568	13000			
Volatile Suspended Solids	mg/L	16	6394	7150	4170	2115	7110	23	8192	10633	3750	2660	8130			
Total Dissolved Solids	mg/L	25	7047	5600	4890	3695	8680	31	5373	3764	4740	2933	6018			
Total Nitrogen	mg/L	25	1294	670	1120	810	1680	31	1354	768	1010	670	2000			
Total Kjeldahl Nitrogen	mg/L	25	1326	693	1141	820	1818	31	1446	781	1330	670	2220			
Ammonia-Nitrogen	mg/L	20	743	649	409	205	1263	25	539	555	303	144	745			
Total Phosphorus	mg/L	25	296	254	179	144	399	31	271	220	213	151	291			
Total Dissolved P	mg/L	25	89	46	88	49	109	31	83	39	91	45	112		***	
Soluble Reactive P	mg/L	25	81	59	55	40	100	31	74	46	63	39	95		**	
Potassium	mg/L	29	2809	2431	1880	1505	2790	34	2289	1648	2020	1280	2545			
Calcium	mg/L	29	309	323	224	131	402	34	276	305	220	109	302		*	
Magnesium	mg/L	29	116	130	73	46	141	34	117	133	68	48	116		**	
Sodium	mg/L	29	153	135	108	91	149	34	113	90	96	63	129			
Sodium Adsorption Ratio	-	29	2.29	2.10	1.52	1.08	2.13	34	1.79	1.38	1.38	0.93	2.27		**	
Chloride	mg/L	29	628	384	509	427	673	34	569	380	493	390	570			
Sulphate-Sulphur	mg/L	29	1382	1042	1060	814	1445	34	1092	794	986	683	1213		*	
Electrical Conductivity	mS/cm	29	11.23	8.15	7.37	6.13	14.00	34	9.35	5.59	7.70	6.44	11.98		*	**
pH	-	29	7.6	0.3	7.6	7.4	7.7	34	7.6	0.2	7.6	7.5	7.7			
Aluminum	mg/L	20	72	72	39	23	124	27	10	7	8	4	17	**		
Arsenic	mg/L	29	128	119	75	34	144	34	0.04	0.04	0.03	0.02	0.05	*		
Boron	mg/L	18	0.34	0.48	0.14	0.05	0.33	25	0.54	0.36	0.50	0.25	0.66			
Barium	mg/L	29	0.36	0.21	0.25	0.25	0.35	34	1.9	2.7	0.7	0.5	2.2	*	*	
Cadmium	mg/L	20	9.8	15.5	2.4	0.9	8.9	27	0.004	0.003	0.003	0.002	0.006			
Chromium	mg/L	25	0.006	0.005	0.005	0.003	0.008	31	0.06	0.08	0.03	0.02	0.05	*		
Copper	mg/L	29	0.57	1.25	0.11	0.05	0.34	34	3.0	3.3	1.6	1.1	3.9		*	
Iron	mg/L	20	4.2	4.2	1.7	1.0	8.1	27	20	12	18	9	30	**		
Lead	mg/L	20	0.090	0.082	0.046	0.025	0.150	27	0.015	0.010	0.012	0.007	0.020	**		
Nickel	mg/L	25	0.83	1.46	0.27	0.11	0.69	31	0.20	0.32	0.08	0.05	0.12	*		
Selenium	mg/L	20	0.046	0.027	0.040	0.027	0.052	27	0.042	0.028	0.034	0.027	0.059			
Zinc	mg/L	29	20.1	22.8	7.0	4.3	37.2	34	12.0	12.9	5.1	3.5	14.4	*	*	

*Significance is assigned as $P<0.05$ (*), $p<0.01$(**), and $P<0.001$(***) using Wald tests. F = floor and E = event.

Table C3. Summary statistics and significance of fixed effects for event-based export of water quality parameters measured in runoff emitting from feedlot alleys containing clay or RCC floor substrates.

Parameter	Unit	Clay Floors						RCC Floors						Significance of Fixed Effects*		
		N	Mean	sd	Median	25%	75%	N	Mean	sd	Median	25%	75%	F	E	F × E
Total Suspended Solids	kg/ha	16	152	112	109	68	200	20	386	259	315	217	552	*		
Volatile Suspended Solids	kg/ha	13	92	57	95	41	137	17	331	203	307	199	442	**		
Total Dissolved Solids	kg/ha	18	101	72	78	40	152	21	252	151	229	117	400	**		
Total Nitrogen	kg/ha	14	21.8	16.5	16.3	12.3	25.2	18	56.5	30.9	46.9	32.8	87.8	**		
Total Kjeldahl Nitrogen	kg/ha	12	22.4	17.8	16.3	9.8	32.2	14	60.7	34.0	56.0	29.0	101.9	**		
Ammonia-Nitrogen	kg/ha	10	6.6	4.4	4.7	3.8	11.8	12	14.4	8.0	12.6	7.0	19.8	*		
Total Phosphorus	kg/ha	14	5.1	5.2	2.8	2.2	5.7	18	14.2	10.0	11.3	5.4	20.9	**		
Total Dissolved P	kg/ha	14	2.0	1.5	1.3	1.1	2.4	18	6.1	4.1	5.2	2.4	8.0	**		
Soluble Reactive P	kg/ha	14	1.3	1.3	0.9	0.5	1.5	18	4.1	3.8	2.7	1.4	5.8	**		
Potassium	kg/ha	18	41.9	28.1	29.8	21.4	61.5	21	110	84	90	47	147	**		
Calcium	kg/ha	18	5.1	4.1	3.7	1.7	8.0	21	13.0	10.7	8.5	4.3	17.5	**	*	
Magnesium	kg/ha	18	2.1	1.6	1.5	0.8	2.9	21	6.0	4.5	6.2	2.3	7.8	**	*	
Sodium	kg/ha	18	2.2	1.4	1.9	1.0	3.6	21	5.4	3.1	4.9	2.5	8.2	**		
Chloride	kg/ha	18	10.9	7.5	8.8	5.2	14.5	21	30	16	28	17	45	**		
Sulphate-Sulphur	kg/ha	18	22.5	19.0	17.6	8.1	30.0	21	63	44	55	25	95	**		
Aluminum	g/ha	17	1418	1586	812	342	2002	21	713	613	511	157	1089			
Arsenic	g/ha	17	2.16	2.04	1.77	0.36	3.27	21	1.87	1.35	1.27	0.77	3.14			
Barium	g/ha	17	17.0	6.6	17.0	12.3	21.7	21	51	41	41	12	78			
Cadmium	g/ha	17	47.0	54.3	26.3	14.1	63.5	21	0.23	0.20	0.15	0.07	0.37			
Chromium	g/ha	17	0.12	0.11	0.09	0.05	0.18	21	1.92	1.59	1.61	0.53	2.79			
Copper	g/ha	17	2.56	2.57	1.47	0.73	3.92	21	101	81	66	33	174	*		
Iron	g/ha	17	2364	2289	2127	762	3039	21	1197	810	1094	456	1904			
Lead	g/ha	17	1.72	1.66	1.34	0.54	2.52	21	0.91	0.68	0.80	0.24	1.58			
Nickel	g/ha	17	5.74	4.74	4.43	2.07	8.46	21	5.4	3.6	5.1	2.8	8.4			
Selenium	g/ha	17	0.95	0.81	0.66	0.39	1.44	21	2.6	2.2	1.6	0.7	4.2	*		
Zinc	g/ha	17	147	140	97	57	182	21	402	365	260	102	648	*		

*Significance is assigned as $P<0.05$ (*), $p<0.01$(**), and $P<0.001$(***) using Wald tests. F = floor and E = event.

Table C4. Summary statistics and pairwise comparisons for soil quality parameters analyzed according to depth zones and pen floor substrates. Pairwise comparisons were performed on depth zones within floor types (Depth|Floor) and floor types within depth zones (Floor|Depth).

Parameter (unit)	Unit	Depth*	Clay (n = 9)			RCC (n = 9)			Pairwise Comparisons**		
									Depth|Floor		Floor|Depth
			Mean	sd	Median	Mean	sd	Median	Clay	RCC	RCC v Clay
Total Organic Carbon	%	Clay	1.13	0.24	1.06	0.99	0.34	0.92	a	a	
		NS1	1.41	0.40	1.44	1.31	0.38	1.38	ab	a	
		NS2	1.03	0.32	1.06	1.10	0.30	1.06	b	a	
		NS3	0.99	0.38	0.96	0.96	0.30	0.87	b	a	
Total Nitrogen	%	Clay	0.12	0.03	0.10	0.10	0.05	0.10	a	a	
		NS1	0.16	0.04	0.15	0.14	0.03	0.14	b	b	
		NS2	0.11	0.04	0.10	0.12	0.03	0.12	a	ab	
		NS3	0.10	0.05	0.10	0.11	0.03	0.11	a	ab	
Total Available Nitrogen	mg/kg	Clay	236	68	250	146	72	109	a	a	*
		NS1	212	79	233	154	35	149	ab	a	
		NS2	154	55	170	138	34	147	bc	a	
		NS3	123	79	111	127	44	129	c	a	
Available Ammonia-Nitrogen	mg/kg	Clay	234	68	250	131	81	109	a	a	*
		NS1	211	79	233	154	35	149	ab	a	
		NS2	154	55	170	137	36	147	bc	a	
		NS3	123	80	111	127	44	126	c	a	
Available Phosphate-Phosphorus	mg/kg	Clay	41.9	50.8	22.4	32.7	53.0	6.2	a	ab	
		NS1	59.2	27.9	56.0	83.6	64.5	47.5	a	a	
		NS2	24.9	22.7	22.2	49.8	47.7	28.6	a	ab	
		NS3	15.5	12.5	12.3	18.2	19.4	12.9	a	b	
Potassium	mg/kg	Clay	259	195	178	151	73	131	a	a	
		NS1	260	85	264	210	31	202	a	a	
		NS2	146	78	156	163	56	156	b	a	
		NS3	84	49	66	118	55	104	b	a	
Calcium	mg/kg	Clay	260	28	269	266	45	275	a	a	
		NS1	66	52	57	34	12	42	b	b	
		NS2	47	53	30	34	18	34	b	b	
		NS3	30	6	31	35	15	33	b	b	
Magnesium	mg/kg	Clay	236	55	227	231	40	233	a	a	
		NS1	70	48	61	45	25	34	b	b	
		NS2	40	41	27	36	26	21	b	b	
		NS3	27	14	26	28	10	28	b	b	
Sodium	mg/kg	Clay	214	38	208	225	34	225	a	a	
		NS1	101	31	105	112	28	98	b	b	
		NS2	69	33	64	92	33	84	bc	bc	
		NS3	55	28	63	71	18	74	c	c	
Sodium Adsorption Ratio	-	Clay	3.1	0.4	3.0	3.2	0.4	3.1	ab	a	
		NS1	3.6	1.0	3.7	5.1	1.0	5.0	b	b	*
		NS2	3.1	0.9	2.9	4.8	1.2	5.1	ab	b	
		NS3	2.7	0.8	3.0	3.8	1.2	3.8	b	a	

Parameter (unit)	Unit	Depth*	Clay (n = 9)			RCC (n = 9)			Pairwise Comparisons**		
									Depth|Floor		Floor|Depth
			Mean	sd	Median	Mean	sd	Median	Clay	RCC	RCC v Clay
pH	-	Clay	8.1	0.1	8.1	8.1	0.2	8.1	a	a	
		NS1	8.1	0.1	8.1	8.0	0.2	8.0	a	ab	
		NS2	8.1	0.2	8.0	7.9	0.2	8.0	a	b	
		NS3	7.9	0.1	7.9	7.9	0.1	7.9	b	b	
Electrical Conductivity	dS/cm	Clay	7.1	2.0	6.4	6.3	0.8	6.4	a	a	*
		NS1	5.2	1.2	5.1	4.6	0.6	4.4	b	b	
		NS2	3.6	1.2	3.2	4.1	0.9	4.0	c	b	
		NS3	2.6	0.7	2.5	3.5	0.7	3.4	c	b	
Chloride	mg/kg	Clay	402	152	370	297	111	262	a	a	*
		NS1	331	93	375	271	77	268	a	a	
		NS2	218	72	229	259	66	258	b	a	
		NS3	185	82	187	257	39	256	b	a	
Sulphate-Sulphur	mg/kg	Clay	2101	447	2240	1930	199	1880	a	a	
		NS1	767	540	437	644	414	617	b	b	
		NS2	390	403	266	415	297	282	b	b	
		NS3	270	207	223	231	140	186	b	b	
Arsenic	mg/kg	Clay	6.62	0.70	6.60	6.72	0.65	6.64	a	a	
		NS1	5.08	0.36	5.03	4.76	0.51	4.88	b	b	
		NS2	4.84	0.42	4.83	5.04	0.77	5.13	b	b	
		NS3	5.01	0.53	5.14	4.89	0.78	4.74	b	b	
Barium	mg/kg	Clay	199	22	202	216	30	217	a	a	
		NS1	154	18	157	134	22	141	b	b	
		NS2	150	25	155	148	28	146	b	b	
		NS3	145	29	146	153	39	155	b	b	
Boron	mg/kg	Clay	199	22	202	216	30	217	a	a	
		NS1	154	18	157	134	22	141	b	b	
		NS2	150	25	155	148	28	146	b	b	
		NS3	145	29	146	153	39	155	b	b	
Beryllium	mg/kg	Clay	0.55	0.08	0.56	0.54	0.06	0.54	a	a	
		NS1	0.37	0.09	0.36	0.32	0.07	0.35	b	b	
		NS2	0.35	0.09	0.34	0.35	0.07	0.34	b	b	
		NS3	0.33	0.08	0.34	0.36	0.09	0.36	b	b	
Cadmium	mg/kg	Clay	0.247	0.014	0.248	0.269	0.031	0.271	a	a	
		NS1	0.233	0.046	0.253	0.218	0.021	0.220	ab	a	
		NS2	0.230	0.049	0.209	0.233	0.035	0.236	ab	a	
		NS3	0.225	0.044	0.236	0.240	0.039	0.238	b	a	
Chromium	mg/kg	Clay	19.5	2.5	19.6	19.4	3.6	19.2	a	a	
		NS1	11.6	2.5	12.2	9.7	1.9	10.0	b	b	
		NS2	10.9	2.9	12.3	11.3	3.2	11.5	b	b	
		NS3	10.6	2.9	11.1	10.5	2.0	10.3	b	b	
Cobalt	mg/kg	Clay	7.35	0.93	7.13	7.63	0.93	7.44	a	a	
		NS1	4.81	0.62	4.74	4.31	0.50	4.46	b	b	
		NS2	4.48	0.80	4.71	4.55	0.69	4.71	b	b	

Parameter (unit)	Unit	Depth*	Clay (n = 9)			RCC (n = 9)			Pairwise Comparisons**		
									Depth|Floor		Floor|Depth
			Mean	sd	Median	Mean	sd	Median	Clay	RCC	RCC v Clay
		NS3	4.40	0.76	4.54	4.48	0.72	4.33	b	b	
Copper	mg/kg	Clay	16.0	1.2	15.9	16.1	1.3	16.2	a	a	
		NS1	11.3	2.4	11.8	9.9	1.8	10.3	b	b	
		NS2	9.4	2.1	9.6	9.8	1.7	10.1	b	b	
		NS3	9.8	4.6	8.6	8.6	1.6	8.3	b	b	
Lead		Clay	8.05	0.69	8.24	8.15	0.78	8.12	a	a	
		NS1	5.78	1.11	5.84	5.13	0.55	5.14	b	b	
		NS2	5.44	1.26	5.39	5.32	0.74	5.25	b	b	
		NS3	5.20	0.95	5.31	5.35	0.78	5.23	b	b	
Mercury	mg/kg	Clay	0.033	0.016	0.031	0.032	0.008	0.033	a	a	
		NS1	0.018	0.009	0.019	0.014	0.005	0.013	b	b	
		NS2	0.017	0.006	0.017	0.015	0.006	0.016	b	b	
		NS3	0.027	0.025	0.020	0.015	0.006	0.013	ab	b	
Molybdenum	mg/kg	Clay	0.80	0.07	0.81	0.81	0.10	0.80	a	a	
		NS1	0.60	0.11	0.59	0.53	0.10	0.54	b	b	
		NS2	0.50	0.09	0.52	0.54	0.19	0.52	b	b	
		NS3	0.50	0.15	0.46	0.50	0.15	0.50	b	b	
Nickel	mg/kg	Clay	19.9	1.8	19.7	21.2	2.5	20.8	a	a	
		NS1	13.2	2.0	12.9	11.7	1.7	11.9	b	b	
		NS2	12.6	2.3	13.3	12.6	2.1	12.7	b	b	
		NS3	12.5	2.4	12.9	12.4	2.0	12.3	b	b	
Selenium	mg/kg	Clay	0.37	0.11	0.34	0.33	0.06	0.33	a	a	
		NS1	0.22	0.07	0.24	0.20	0.06	0.21	b	b	
		NS2	0.13	0.06	0.10	0.19	0.09	0.21	bc	b	
		NS3	0.11	0.04	0.10	0.13	0.07	0.10	c	b	
Vanadium	mg/kg	Clay	32.2	4.6	33.1	29.3	4.9	28.6	a	a	
		NS1	21.3	4.3	22.9	18.5	3.6	19.0	b	b	
		NS2	20.5	4.8	21.9	20.4	4.2	21.0	b	b	
		NS3	20.0	4.3	21.6	19.9	4.6	19.6	b	b	
Zinc	mg/kg	Clay	58.0	5.1	58.7	57.4	6.3	55.1	a	a	
		NS1	47.3	10.6	49.7	41.8	7.8	40.5	b	b	
		NS2	38.2	10.2	39.1	40.9	5.6	40.0	c	b	
		NS3	35.7	9.3	36.3	36.2	7.0	33.9	c	b	

***In pairwise comparisons between depth zones within floor types, different letters indicate significant differences ($p<0.05$). In pairwise comparisons between floor types within depth zones, asterisks (*) denote significant differences ($p<0.05$).**

APPENDIX D: MANURE COMPOSITION AND QUANTITY

D.1 Abstract

It has been reported in the literature that the type of the surface of feedlot pen floors may affect the quantity and quality of manure that being scraped and removed from the feedlot.The impact of the type of feedlot floors on the quality and quantity of manure in the feedlot pens has been investigated in this part of the study. Manure samples had been collected from the study site and analysed for physical and chemical properties. In addition, manure hauling records had been obtained from the feedlot operator. The analysis of manure samples showed that manure from CLAY pens had more ash contents compared to manure from RCC pens. It also indicated that manure in RCC pens was rich in macronutrients compared to manure from CLAY pens and had less heavy metals. The analysis of manure hauling records confirms that more manure was being hauled from CLAY pens compared to mixed and RCC pens. The results indicated that about 40.0 % less manure per head-days was scraped from RCC pens compared to manure harvested from clay pens. Due to the lower ash and higher nutrient content, manure from RCC pens is likely to generate higher agronomic value than manure from CLAY pens. Owing to the reduced volumes of manure collected from RCC pens, costs associated with manure hauling and disposal will be much lower for RCC pens compared with CLAY pens.

D.2 Objectives

The purpose of this project part was to assess the physical and chemical of properties of manure generated in the feedlot study pens as well as to provide more information on the influence of the feedlot pen floor on the quantity and the quality of manure collected from the feedlot pens after cleaning.

D.3 Materials and Methods

D.3.1 Manure Sample Collection

Manure samples were collected from the feedlot study pens according to Alberta Agriculture and Forestry's solid manure sampling guidelines (AF, 2008). A hundred and fourteen manure samples were collected from the feedlot study pens in Spring-Fall of 2017 and Spring-Fall of 2018 (41 samples from RCC pens; 62 samples from RCC pens and 11 samples from mixed pens).   All collected manure samples were stored in a freezer until they were shipped to the testing laboratory for analysis.

D.3.2 Manure and Clay Sample Analysis

Chemical and physical analysis of manure samples were conducted at Central Testing Laboratory (Winnipeg, MB). The laboratory uses an established procedure for preparation the manure samples for testing and analysis (CTL-MA (2H) SOP and CTL MRSOP). Laboratory testing methodologies for manure samples are detailed in Table D1. All the samples were analyzed for Moisture content, pH, Dry matter, Ash contents, total Nitrogen, Ammonium-N, Nitrate-N, total Phosphorus, Phosphorus Pentoxides, total Potassium, Potassium Oxide, Copper, Iron, Zinc, Boron, Molybdenum, Sodium, Calcium, Sulphur, Manganese and Magnesium. All analysis results were reported in dry matter-basis (DM) except Moisture content, pH, and Ammonium-N, which were reported in wet-basis. Only one sample of clay was collected from clay pile at feedlot. This clay is usually used to repair and maintain the surface of clay pens in the feedlot. The clay sample was analyzed for nutrient contents at CTL.

Table D1. Manure Testing Methodologies

Test	**Method**	**Test**	**Method***
Mineral	AOAC 923.01	Potassium Oxides	Calculation
Ash	AOAC 923.03	Total nitrogen	Modification of AOAC 990.03
Ammonium	AOAC 941.04	Mineral	Modification of AOAC 968.08, 935.13A
pH	AOAC 943.02	Moisture	Moisture Analyzed AOAC 930.15
Nitrate Total	AOAC 986.31	Moisture	Moisture Received AOAC 922.02
Phosphorus Pentoxide	Calculation		

*AOAC: Association of Official Analytical Chemists

D.3.4 Statistical Analysis

The data were analyzed according to the General Linear Model (GLM) procedure using the statistical software package *R (*Version 3.5.2). The model included effects of the type of the feedlot pen surface (Clay or RCC) on manure physical and chemical properties.

D.3.5 Manure Hauling Records

Manure scraping and pen cleaning at this feedlot typically occurs twice a year, in spring and fall. Manure removal records were obtained from the feedlot operator for years 2016, 2017 and 2018. Some of Alberta Agriculture and Forestry staff involved in this project conducted a number of observations during manure removal to confirm the accuracy of the manure hauling records recorded by the feedlot trucks hauling operators. The majority of records data were compiled and summarized except the ones deemed to be incomplete. The amount of manure removed from the study was reported as the amount of manure removed in kg per head-days.

D.4 Results and Discussion

D.4.1 Manure Composition

The manure nutrient composition from the study pens are comparable with those reported in published literature (Table D2), except that the values of total nitrate of manure samples collected in the fall of 2018. These samples were very low compared to other samples collected from this feedlot and the values of nitrate in cattle feedlots manure reported in published literature. The laboratory repeated these analyses and concluded that it was not an error in their analysis. Dietary and weather conditions at the time of manure sampling are likely the factors that may contribute to low nitrate contents of manure sampled from all pen floor types.

Table D2. Comparison of macronutrients of manure collected from RCC study site to macronutrients of feedlot manure reported in other studies**.**

	Total N (% db)	**Phosphorus (% db)**	**Potassium (% db)**
RCC Study (this study) Clay Pens	**1.90**	**0.81**	**2.09**
RCC Study (this study) RCC Pens	**2.41**	**1.05**	**2.41**
Alberta Feedlot Guide	2.00	n/a	n/a
Australia Feedlot Guide	2.18	0.80	1.86
Kissinger et al. (2007)	1.28	0.64	1.35
Zhang and Hamilton (2017)	1.97	0.75	1.98
Egbball and Power (1994)	1.90	0.64	2.00

Results of manure analysis are summarized in Table D3. Manure from clay pens had more ash contents compared to manure from RCC pens ($p<0.01$). It was expected that clay pens would have more clay, as defined by ash content, mixed with manure compared to RCC pens (Woodbury et al., 2007; Sweeten et al., 2013).

The type of pen floor surface was also found to influence the moisture content of the manure. The results showed that on average, manure sampled from RCC pens had higher moisture contents than manure scraped from clay pens ($p= 0.0343$). This finding was not anticipated since it was expected that manure in RCC pens should be drier than the manure in clay pens due to good drainage in RCC pens. For example, Woodbury et al. (2007) found that the average moisture content of manure from soil-surfaced pens was 56.3%, while manure from fly-ash stabilized pens had a moisture content of only 26%.

Significant differences were observed for manure properties of Dry Matter, Moisture, pH, Boron and Sodium, Copper, Iron, Molybdenum, Phosphorus, Phosphorus Pentoxide, Potassium, Potassium Oxide, Sodium, Sulphur, total Nitrogen, and Zinc (Table D3). Presence of heavy metals in manure in clay pens may contribute to increasing the level of heavy metals in the runoff from clay pens. Manure from RCC pens is rich in macronutrients; this suggests that the agronomical and fertilizer value of manure harvested from RCC pens will be higher compared to manure scraped from clay pens.

D.4.2 Manure Quantity

The average amount of manure in kg removed per head-days are 8.21, 5.68 and 4.93 for clay, mixed, and RCC pens respectively. This analysis confirms that more manure was being hauled from clay pens compared to mixed and RCC pens. The results indicated that about 40.0 % less manure per head-days was scraped from RCC pens compared to manure harvested from clay pens. This result does not agree with the chemical analysis of manure samples collected from the study pens. The analysis indicated that the difference in average Ash content between Clay pens and RCC pens was 16.48%, which we expect that it would be equivalent to the difference in the mass of manure removed from clay pens compared to RCC pens. However, a study conducted by Woodbury et al. (2013) found that using Pond Ash to surface the feedlot pens reduced the total solids collected by 34% compared to soil-surfaced pens. The cost of hauling of manure from RCC pens will be much lower than the cost of hauling manure from mixed or RCC pens.

Table D3: Nutrient analysis of manure collected from RCC and Clay pens reported on a dry-basis. (± wet basis)

Manure Chemical Property	Clay Mean	RCC Mean	*P* value	Clay Min-Max	RCC Min-Max
Ammonium (ppm)±	2719	2854	NS	954-4787	1231-4737
Ash (%)	39.54	22.76	***	20.47-60.63	13.71-48.37
Boron (ppm)	17.05	19.52	**	10.09-32.93	11.76-34.82
Calcium (%)	1.82	1.80	NS	1.29-2.46	1.05-3.30
Copper (ppm)	41.14	50.89	***	31.45-54.63	34.95-85.16
Dry Matter (%)±	32.95	28.98	**	14.86-52.23	14.51-47.47
Iron (ppm)	5963	2294	***	1897-13598	648-10764
Magnesium (%)	0.69	0.68	NS	0.48-1.03	0.44-1.09
Manganese (ppm)	200.59	182.38	**	126.27-270.02	114.12-319.02
Moisture (%)±	67.13	71.02	**	47.77-85.14	52.53-85.49
Molybdenum (ppm)	13.56	7.28	***	4.04-53.84	2.42-22.46
Nitrates N (%)	3.85	4.81	NS	2.36-40.61	3.31-41.3
pH±	8.06	8.24	**	7.15-8.90	7.48-8.75
Phosphorus (%)	0.81	1.05	***	0.52-1.25	0.66-1.37
Phosphorus Pentoxide (%)	1.85	2.40	***	1.19-2.86	1.51-3.14
Potassium (%)	2.09	2.84	***	1.41-3.74	2.0-3.82
Potassium Oxide (%)	2.51	3.41	***	1.69-4.49	2.4-4.58
Sodium (%)	0.10	0.11	**	0.06-.0.10	0.05-0.17
Sulphur (%)	0.47	0.58	***	0.34-0.64	0.01-0.78
Total Nitrogen (%)	1.90	2.41	***	1.21-2.62	1.78-3.21
Zinc (ppm)	218.17	282.62	***	149.81-305.39	184.98-521.00

APPENDIX E: AIR QUALITY AND GREENHOUSE GAS EMISSIONS

E1. Abstract

The effects of three pen floor surface treatments, Clay, Mixed and RCC on NH_3 and GHG emissions from a commercial feedlot were evaluated between July and September 2017, and May and September 2018. Closed static flux chambers with enclosed acidified foam pads were used to capture NH_3 emissions off the pen floor surfaces at twelve sampling locations per pen. Similarly, GHGs at twelve sampling locations per pen were extracted with a syringe from the airspace enclosed by a static flux chamber at 15 min intervals for up to 1 h. The captured NH_3 was extracted from the foam pads with a solution of KCl and analyzed analytically in a laboratory. The GHG samples, on the other hand, were analyzed in a laboratory with a GC. Median NH_3 emission rates were 0.432 $g.m^{-2}.h^{-1}$, 0.429 $g.m^{-2}.h^{-1}$ and 0.405 $g.m^{-2}.h^{-1}$ from the Clay, Mixed and RCC treatment pens, respectively. Comparatively, there were no statistical differences in median NH_3 emission rates between the floor treatments. Median N_2O emission rates were 1.55 $ng.m^{-2}.s^{-1}$, 2.42 $ng.m^{-2}.s^{-1}$ and -1.59 $ng.m^{-2}.s^{-1}$ from the Clay, Mixed and RCC treatment pens, respectively. Comparatively, there were no significant differences in median N_2O emission rates between the Clay and Mixed floor treatments, but both differed significantly from the RCC treatment pen median emission rate. Similarly, median CH_4 emission rates were not significantly different between the Clay and Mixed treatments, but were both significantly different from the RCC treatment. Median CH_4 emission rates were 0.2 $\mu g.m^{-2}.s^{-1}$, 0.2 $\mu g.m^{-2}.s^{-1}$ and 0.1 $\mu g.m^{-2}.s^{-1}$ from the Clay, Mixed and RCC treatment pens, respectively. There were no statistical differences in median CO_2 emission rates between the floor treatments. Median CO_2 emission rates were 55.7 $\mu g.m^{-2}.s^{-1}$, 45.8 $\mu g.m^{-2}.s^{-1}$ and 44.0 $\mu g.m^{-2}.s^{-1}$ from the Clay, Mixed and RCC floors, respectively.

E2. Objectives

The objective and deliverable for this aspect of the research project were to:

i) Scientifically quantify ammonia and GHG emissions associated with paved and unpaved pen floor surfaces at a commercial feedlot.

ii) Complete a statistical comparison of the emissions associated with treated and untreated pen floor surfaces, considering possible covariate effects that may be attributable to manure moisture content and ambient air temperature.

E3. Materials and Methods

E.3. 1 Study Site

This research study was conducted on a commercial feedlot with a holding capacity of 10,000-head of cattle. The feedlot comprised of forty large finishing pens, ranging in surface area (based on the pen boundary) between 2,210 m^2 (one pen) and 4,410 m^2 (one pen). Nineteen of the forty pens had a surface area of 3,185 m^2. An additional eleven smaller finishing pens were also located on site, with surface areas ranging between 1,080 m^2 (one pen) and 1,625 m^2 (three pens). In 2016 when the study commenced, the floor surfaces of all eleven smaller finishing pens and nineteen of the forty larger pens constituted of clay material (Clay). Sixteen of the forty pens were retrofitted with RCC material, spanning an estimated 85% of the total pen surface area (RCC), i.e., excluding the area covered by the reinforced concrete apron adjacent to the feed bunk and around the watering trough, and the area of the pen covered by the bedding pack (Fig. A1). Of the remaining five large pens, about half or 50% (i.e., the back half of the pen away from the feed bunk) of each pen's floor surface was paved, presumably with RCC material (Mixed). In October 2017, the pen floors of the eleven smaller finishing pens were retrofitted with RCC material, while seven of the larger pens were retrofitted with RCC material in July 2018.

<u>E.3. 2 Gas Emissions from Feedlot Pen Surfaces</u>

The original intent of the study was to conduct paired comparisons between NH_3 and GHG emissions, respectively, from sixteen Clay pens and sixteen RCC pens at the study site. However, for logistical reasons this was not attainable, and the research team opted for an unbalanced, completely randomized design (Steel et al., 1997), with measurements of emissions from the three pen floor surfaces, i.e., Clay, Mixed and RCC.

In July, August, and September 2017, 120, 36 and 114 NH_3 samples were obtained from randomly selected sampling locations in the Clay, Mixed and RCC floor treatment pens, respectively. Closed static flux, acid trap chambers with acidified foam pads were exposed to NH_3 emissions off the respective pen floors for 1 h. Shortly after the foam pads had been retrieved from the chambers, bagged, and stored in coolers containing frozen ice packs, manure samples from the respective gas sampling locations were collected, and also stored in coolers containing frozen ice packs. The coolers were transported to a research facility where the trapped NH_3 (NH_4^+ ion) was extracted from the foam pads using 100 ml of KCl, poured into sampling jars, and stored in a freezer prior to shipment to an analytical laboratory for analysis. The manure samples were weighed, oven dried at 70 ^oC for 24 h, and then weighed again. Moisture content was determined on a wet basis.

GHG samples were also collected simultaneously with the NH_3 samples in five, 15-min time steps (0 min, 15 min, 30 min, 45 min and 60 min) from independent, randomly selected sampling locations (106, 36 and 103, respectively) in pens with Clay, Mixed and RCC floor surfaces. Air samples enclosed by closed static flux chambers were extracted with a syringe, and injected into exetainer vials that were subsequently stored in a cooler. Manure samples were also collected from the GHG sampling locations after GHG sampling. Similar to the NH_3 samples, the GHG samples were transported to the research facility and stored in a freezer prior to shipment to an analytical laboratory for analysis. The manure samples were weighed, oven dried and weighed again to determine manure moisture content.

Ambient air temperature was monitored over the duration of the feedlot sampling activity via a meteorological station located on site. These data along with barometric pressure data from another meteorological station located in Lethbridge County, were used to determine fluxes of methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2) from the respective sampling locations.

In 2018 (May to September), 264, 96 and 300 samples of NH_3, GHGs, and manure samples were extracted from pens under the Clay, Mixed and RCC floor surface treatments, respectively. Ambient air temperature and barometric pressure were also monitored during the feedlot sampling activity.

E.3.4.3 Statistical Data Analysis

According to EPIC (2009), environmental data are typically skewed (asymmetric), do not meet the assumptions of normality or equal variance, and where outliers exist, these have a tendency to be high. Consequently, all NH_3 emissions, GHG (CH_4, N_2O and CO_2) emissions, manure moisture content and ambient air temperature data associated with each pen floor surface treatment were subjected to the Shapiro-Wilk normality test (McBean and Rovers, 1998). Whereupon the data did not meet the assumption of normality, the non-parametric Kruskal-Wallis rank sum was used to compare differences between all three pen floor surface treatments. In addition, the non-parametric Wilcoxon rank sum test was used to conduct pairwise comparisons between different paired treatments.

In order to assess the possible covariate effects of manure moisture content and ambient air temperature (explanatory variables, potentially) on the gas emissions per pen floor surface treatment (EPIC, 2009), univariate regression analysis of gas emissions vs moisture content and gas emissions vs ambient air temperature, as well as, multiple regression analysis of gas emissions vs moisture content and ambient air temperature, were run. Linear, exponential and polynomial regression coefficients were determined in assessing the univariate regression models, while an adjusted regression coefficient was determined in evaluating the multiple regression model (EPIC, 2009). Graphical plots of gas emissions versus moisture and temperature, with and without emissions greater than 3 times the IQR, provided visual evidence of possible covariate effects of both parameters on gas emissions.

E.4. Results and Discussion

E.4.1 Ammonia Emissions from Different Feedlot Pen Floor Surfaces

The distribution of NH_3 emissions associated with all three pen floor treatments were positively skewed and did not meet the assumptions of normality at $p<0.01$. Median emissions (with and without outliers), means (with and without outliers), maximums (with and without outliers) and minimums are presented in Table E1 below.

Simple linear, exponential and polynomial regression coefficients associated with the regression analyses of NH_3 emissions against the (i) manure moisture content, and (ii) ambient air temperature, are presented in Table E2. In addition, the adjusted regression coefficients of a multiple regression of all three variables, are also presented in Table E2.

The extremely low regression and adjusted regression coefficients signify poor correlation (weak covariance) between the two potential explanatory variables, manure moisture content and ambient air temperature, on relative, hourly NH_3 emissions over the 200-day period. These results suggest that the observed NH_3 emissions associated with each pen floor treatment were not unduly influenced by either extenuating variable, considering all measurements were temporally and spatially independent.

Median, mean, maximum and minimum manure moisture content and ambient air temperature values corresponding to the gas sampling events in the respective feedlot pens under the different treatments are presented in Table E3 above. Interestingly, the moisture contents of manure samples obtained from pens under the RCC treatment were significantly higher ($p<0.01$) compared to samples from pens under the Clay and Mixed floor treatments. Regardless, manure moisture content did not seem to influence NH_3 emissions from pens under the RCC floor treatment, nor did the slightly higher ambient air temperatures, associated with sampling events in the Clay floor treatment pens.

E.4.2 GHG Emissions from Different Feedlot Pen Floor Surfaces

Results of the GHG emissions data analyses for N_2O, CH_4, CO_2 and Total GHGs, based on cumulative GHG emissions on a CO_2-equivalent basis, and manure moisture content and ambient air temperature corresponding to the GHG sampling events are presented and discussed in the sections below.

E.4.2.1 GHG-N_2O Emissions

Figure E6 shows a positively skewed distribution of N_2O emissions associated with the three pen floor treatments, which supports the outcome of the normality tests, with none of the distributions meeting the assumptions of normality ($p<0.01$).

Further visualization of the distribution of each dataset relative to the three pen floor treatments (Fig. E7) suggests that more pronounced denitrification processes occurred in pens under the Clay floor Figure E5 is a visual representation of the relationship between NH_3 emissions, in relation to manure moisture content and ambient air temperature.

Table E4 below presents median (with and without outliers), mean (with and without outliers), maximum (with and without outliers) and minimum N_2O emissions associated with the three pen floor treatments. Of the three, net N_2O emissions from pens under the RCC treatment were negligible, supporting the assertion that the RCC floor treatment did not support substantial populations of denitrifying bacteria.

Regression coefficients associated with the simple regression analyses of N_2O emissions against (i) manure moisture content, and (ii) ambient air temperature, and a multiple regression of all three variables, are presented in Table E5. The low correlation coefficients signify no influence (weak covariance) of manure moisture content or ambient air temperature on N_2O emissions associated with all three treatments. Further evidence of the lack of correlation between the N_2O emissions, manure moisture content and ambient air temperature is shown in Fig. E8.

E.4.2.2 GHG-CH_4 Emissions

Density plots of CH_4 emissions also reflect a positively skewed distribution associated with the three pen floor treatments (Fig. E9). Thus, as expected, the assumptions of normality were not met ($p<0.0001$). Figure E10 shows the distribution of CH_4 emissions with respect to the percentiles and mean values. Again, it seems the pens under Clay floor treatment had more active populations of methanogenic bacteria than those under the other two treatments. Median (with and without outliers), mean (with and without outliers), maximum (with and without outliers) and minimum CH_4 emissions relative to the pen floor treatments are presented in Table E6.

Regression coefficients associated with the simple regression analyses of CH_4 emissions in relation to manure moisture content and ambient air temperature, and a multiple regression of all three variables, are presented in Table E7. Similar to GHG-N_2O results, the correlation is indicative of the absence of influence by manure moisture content or ambient air temperature on CH_4 emissions associated with the three floor treatments. This is also evident in the data presented in Fig. E11.

E.4.2.3 GHG-CO_2 Emissions

Similar to the other two GHGs, density plots of all CO_2 emissions, with respect to each pen floor treatment, also reflect positively skewed distributions (Fig. E12). The nature of the distributions were indicative of the outcome of the normality tests, signifying the assumptions of normality were not met ($p<0.0001$). Figure E13 shows each pen floor treatment distribution relative to the percentiles and mean emission rates.

In assessing the possible influence of manure moisture content and ambient air temperature on CO_2 emissions associated with the various floor treatments, the regression results presented in Table E9 indicate a non-linear influence of both parameters on emissions from the Clay and Mixed treatment pens, but the inkling of a linear or quadratic effect of moisture on CO_2 emissions from the RCC treatment pens. As shown in Fig. E14 it is seemingly apparent that CO_2 emissions from the RCC treatment pens increased with increasing manure moisture content. Although, this was not evident with pens under the other two treatments, the presence of clay beneath the manure layer, and its ability to retain moisture, may have resulted in a similar effect on the rate of aerobic decomposition of carbon present in manure embedded in the clay.

Other than the single outstanding emission experienced at one sampling location in a pen under the Clay treatment (Fig. E13), the distribution of CO_2 emissions across all three floor treatments appeared similar. Median, mean, maximum, and minimum CO_2 emissions relative to the pen floor treatments are presented in Table E8. With no significant differences in CO_2 emissions between the three pen floor treatments, these results suggest the aerobic decomposition of carbon present in the manure was similar across all treatments, regardless of temporal sampling differences.

Median, mean, maximum and minimum manure moisture content and ambient air temperature values corresponding to gas sampling events under the respective pen floor treatments are presented in Table E10. Normality tests indicated that all distributions did not meet the assumptions of normality.

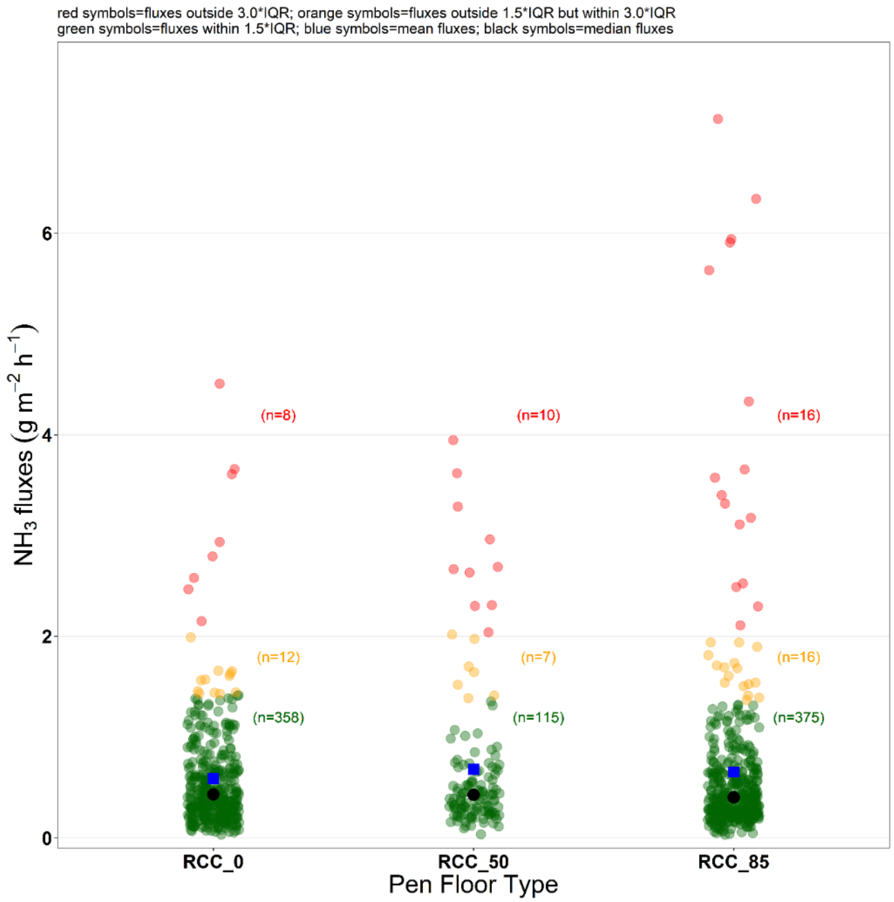

Fig. E4. Distribution of NH_3 emissions at various sampling locations in feedlot pens under different floor treatments.

Table E1. Summary statistics for NH_3 emissions ($g \cdot m^{-2} \cdot h^{-1}$) from different feedlot pen floor treatments

Statistic	**Pen Floor Surface Treatment**		
	Clay	**Mixed**	**RCC**
Median	0.432[a]	0.429[a]	0.405[a]
Mean	0.587	0.683	0.653
Maximum	4.51	3.95	7.13
Minimum	0.033	0.037	0.032

Median values with superscripts of the same letter were not significantly different (p = 0.86)

Table E2. Coefficients of determination between NH_3 emissions, manure moisture content and ambient air temperature.

Model	Pen Floor Surface Treatment		
	Clay	Mixed	RCC
NH_3 = fn{Moisture}			
Linear:	0.04	0.02	0.01
Exponential:	0.00	0.00	0.00
Polynomial:	0.06	0.03	0.04
NH_3 = fn{Temperature}			
Linear:	0.02	0.07	0.01
Exponential:	0.01	0.02	0.00
Polynomial:	0.02	0.07	0.01
NH_3 = fn{Moisture, Temperature}	0.04	0.08	0.03

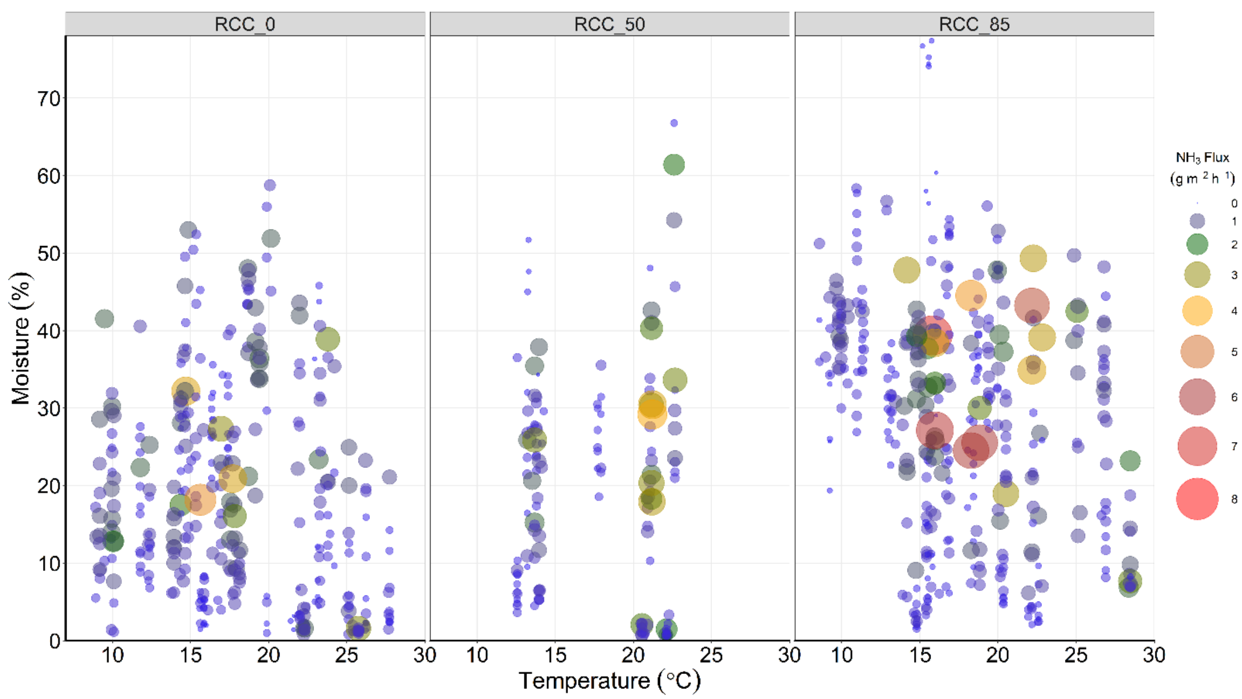

Fig. E5. Scatterplot of NH_3 emissions in relation to temporally and spatially corresponding manure moisture content and ambient air temperature.

Table E3. Summary statistics for manure moisture content (%) and ambient air temperature (°C) with respect to the different pen floor treatments

Statistic	Pen Floor Surface Treatment		
	Clay	**Mixed**	**RCC**
Manure Moisture Content (%)			
Median:	15.3[a]	20.8[a]	30.9[b]
Mean:	18.1	19.6	28.8
Maximum:	58.7	66.8	77.4
Minimum:	0.8	0.6	1.6
Ambient Air Temperature (°C)			
Median:	17.8[a]	17.8[b]	16.9[a,b]
Mean:	18.5	17.5	17.8
Maximum:	27.7	22.7	28.5
Minimum:	8.9	12.6	8.6

Median values with superscripts of the same letter were not significantly different (α = 0.05)

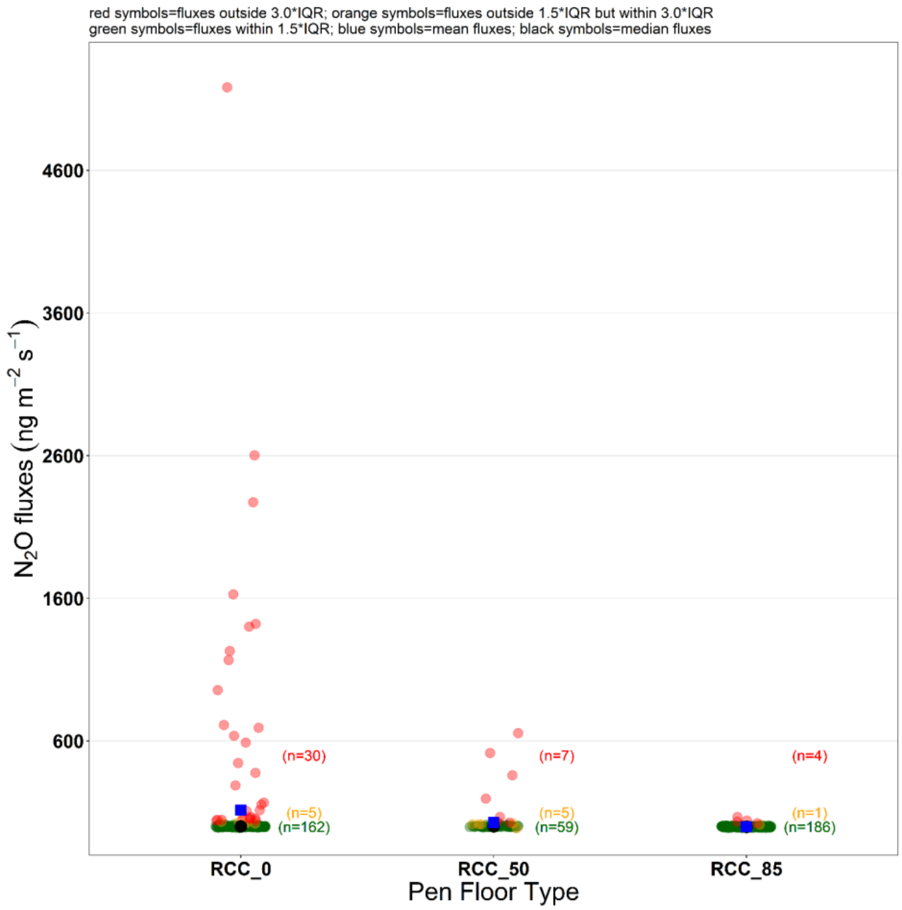

Fig. E7. N_2O emissions at various sampling locations in feedlot pens under different floor treatments.

Table E4. Summary statistics for N_2O emissions ($ng \cdot m^{-2} \cdot s^{-1}$) from different feedlot pen floor treatments

Statistic	**Pen Floor Surface Treatment**		
	Clay	**Mixed**	**RCC**
Median	1.55^a	2.42^a	-1.59^b
Mean	116.43	28.18	0.01
Maximum	5,183	655	67.5
Minimum	-10.9	-12.7	-10.9

Median values with superscripts of the same letter were not significantly different (p = 0.40)

Table E5. Coefficients of determination indicative of correlation between N_2O emissions, manure moisture content and ambient air temperature.

Model	Pen Floor Surface Treatment		
	Clay	Mixed	RCC
N_2O = fn{Moisture}			
Linear:	0.02	0.01	0.06
Exponential:	0.00	0.00	0.00
Polynomial:	0.02	0.04	0.06
N_2O = fn{Temperature}			
Linear:	0.00	0.06	0.01
Exponential:	0.00	0.01	0.00
Polynomial:	0.00	0.06	0.01
N_2O = fn{Moisture, Temperature}	0.01	0.04	0.05

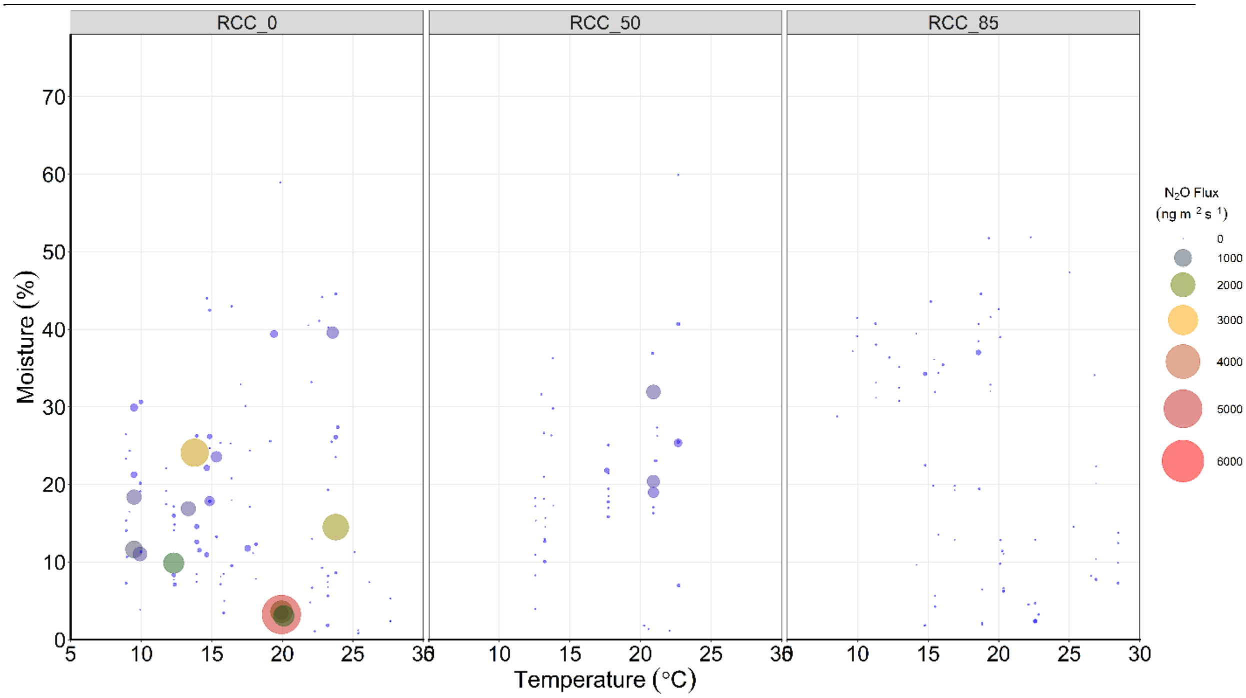

Fig. I-8. Scatterplot of N_2O emissions relative to temporally and spatially corresponding manure moisture content and ambient air temperature values.

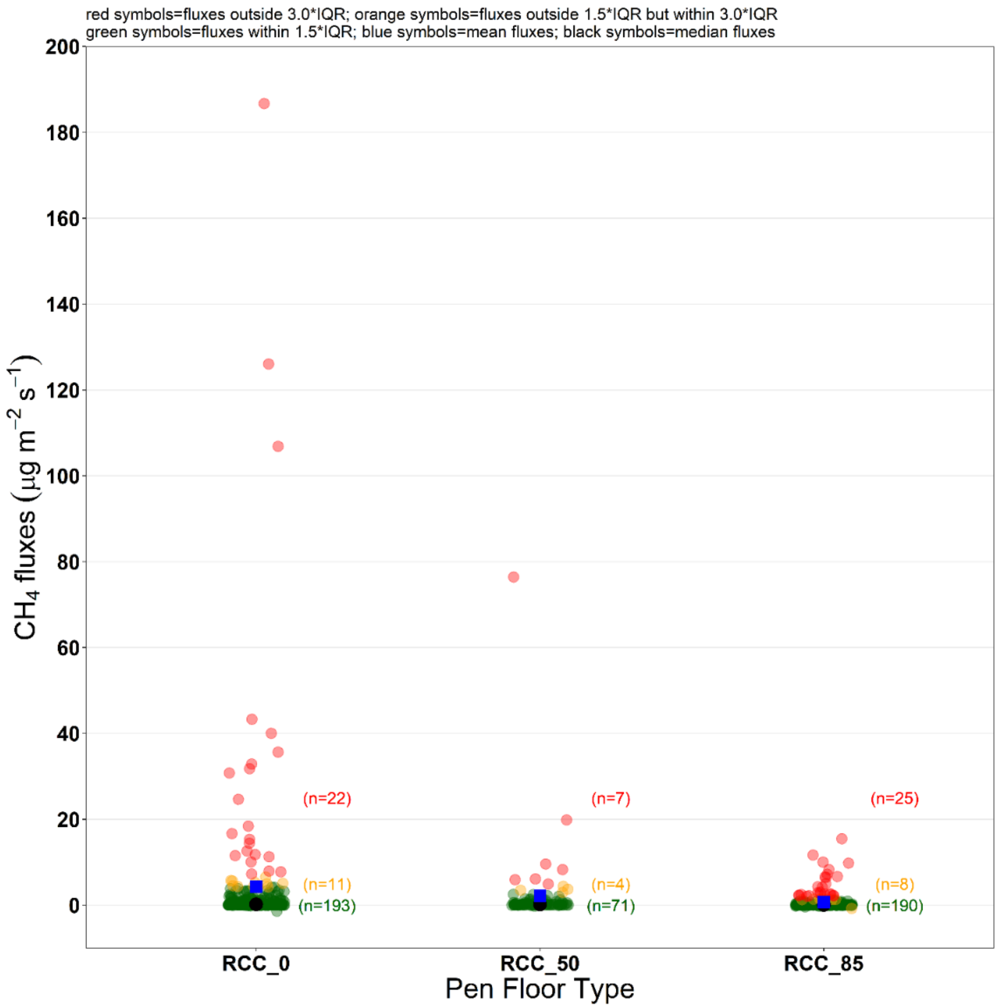

Fig. E10. CH_4 emissions at various sampling locations in feedlot pens under different floor treatments.

Table E6. Summary statistics for CH_4 emissions ($\mu g \cdot m^{-2} \cdot s^{-1}$) from different feedlot pen floor treatments

Statistic	Pen Floor Surface Treatment		
	Clay	Mixed	RCC
Median	0.2[a]	0.2[a]	0.1[b]
Mean	4.3	2.2	0.7
Maximum	186.7	76.4	15.5
Minimum	-1.4	-0.2	-0.8

Median values with superscripts of the same letter were not significantly different (p = 0.92)

Table E7. Coefficients of determination indicative of correlation between CH_4 emissions, manure moisture content and ambient air temperature.

Model	Pen Floor Surface Treatment		
	Clay	Mixed	RCC
CH_4 = fn{Moisture}			
Linear:	0.00	0.00	0.01
Exponential:	0.00	0.00	0.00
Polynomial:	0.01	0.02	0.01
CH_4 = fn{Temperature}			
Linear:	0.01	0.00	0.01
Exponential:	0.00	0.00	0.00
Polynomial:	0.02	0.05	0.01
CH_4 = fn{Moisture, Temperature}	-	-	0.02

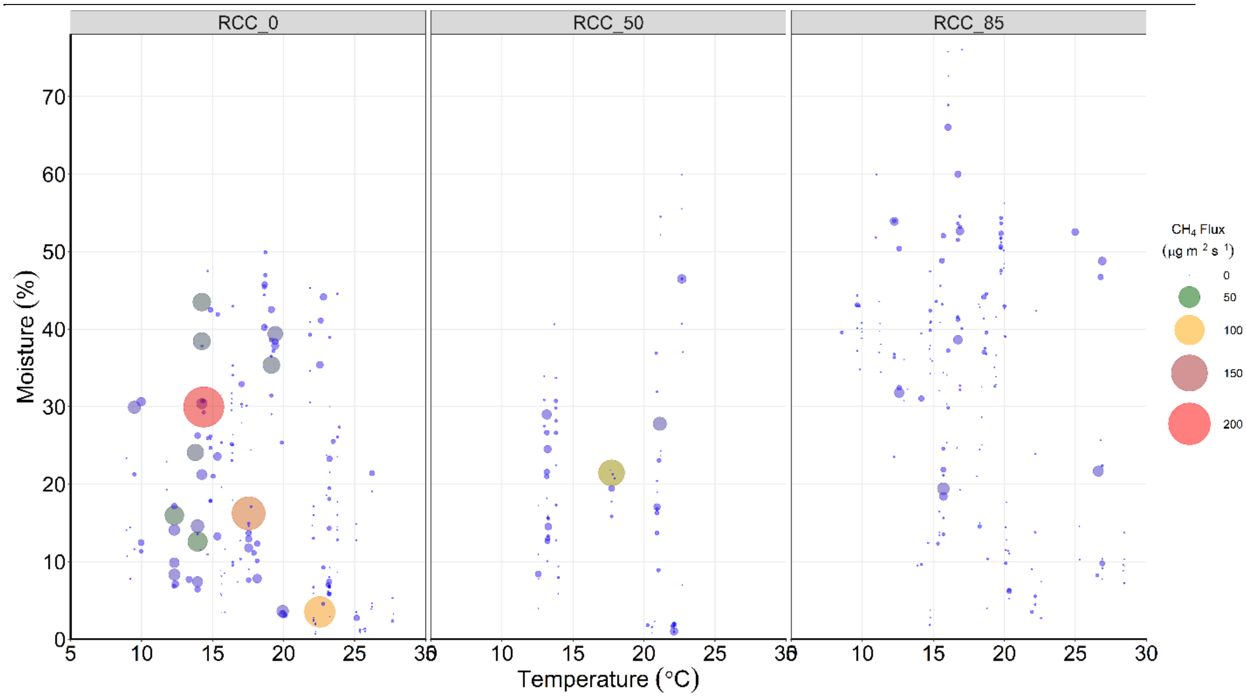

Fig. E11. Scatterplot of CH_4 emissions relative to temporally and spatially corresponding manure moisture content and ambient air temperature values.

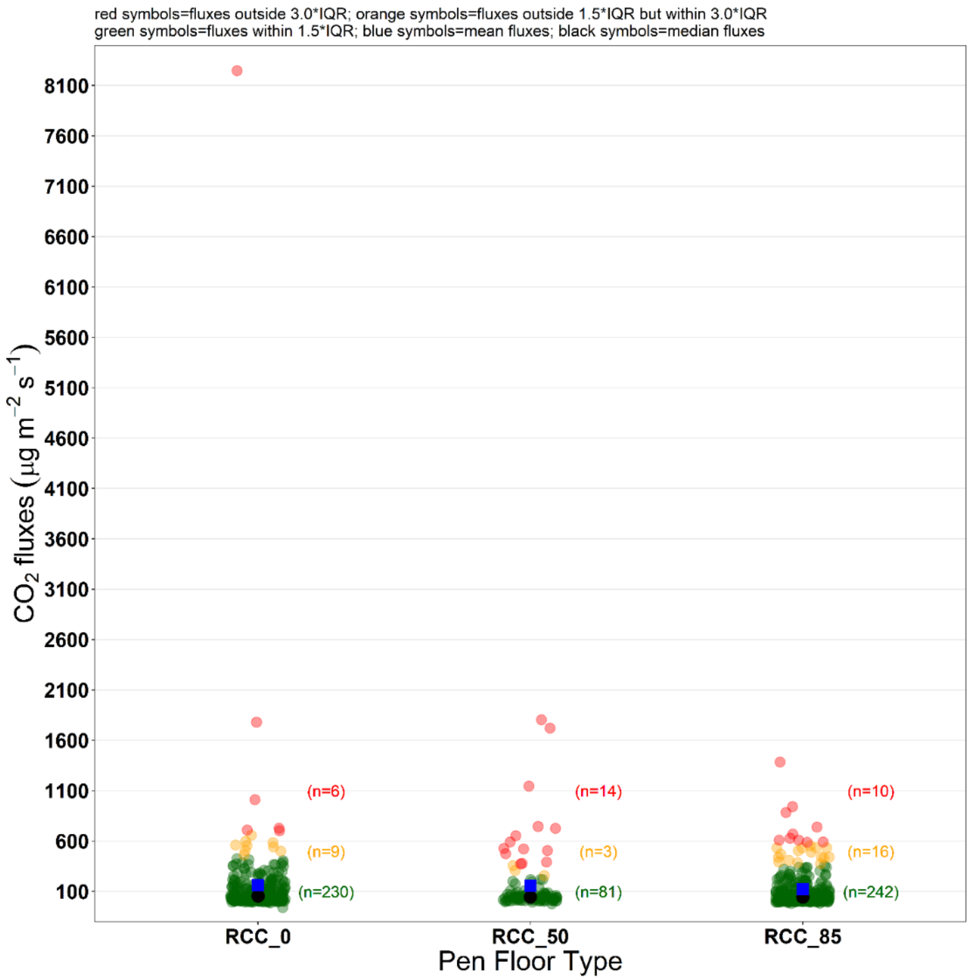

Fig. E13. CO_2 emissions at various sampling locations in feedlot pens under different floor treatments.

Table E8. Summary statistics for CO_2 emissions ($\mu g \cdot m^{-2} \cdot s^{-1}$) from different feedlot pen floor treatments

Statistic	**Pen Floor Surface Treatment**		
	Clay	**Mixed**	**RCC**
Median	55.7[a]	45.8[a]	44.0[a]
Mean	162.9	158.1	121.9
Maximum	8,247	1,804	1,385
Minimum	-59.7	-22.0	-18.8

Median values with superscripts of the same letter were not significantly different (p = 0.59)

Table E9. Regression coefficients between CO_2 emissions, manure moisture content and ambient air temperature.

Model	Pen Floor Surface Treatment		
	Clay	Mixed	RCC
CO_2 = fn{Moisture}			
Linear:	0.03	0.03	0.15
Exponential:	0.00	0.00	0.00
Polynomial:	0.03	0.06	0.15
CO_2 = fn{Temperature}			
Linear:	0.00	0.02	0.00
Exponential:	0.00	0.00	0.00
Polynomial:	0.01	0.04	0.00
CO_2 = fn{Moisture, Temperature}	0.03	0.03	0.15

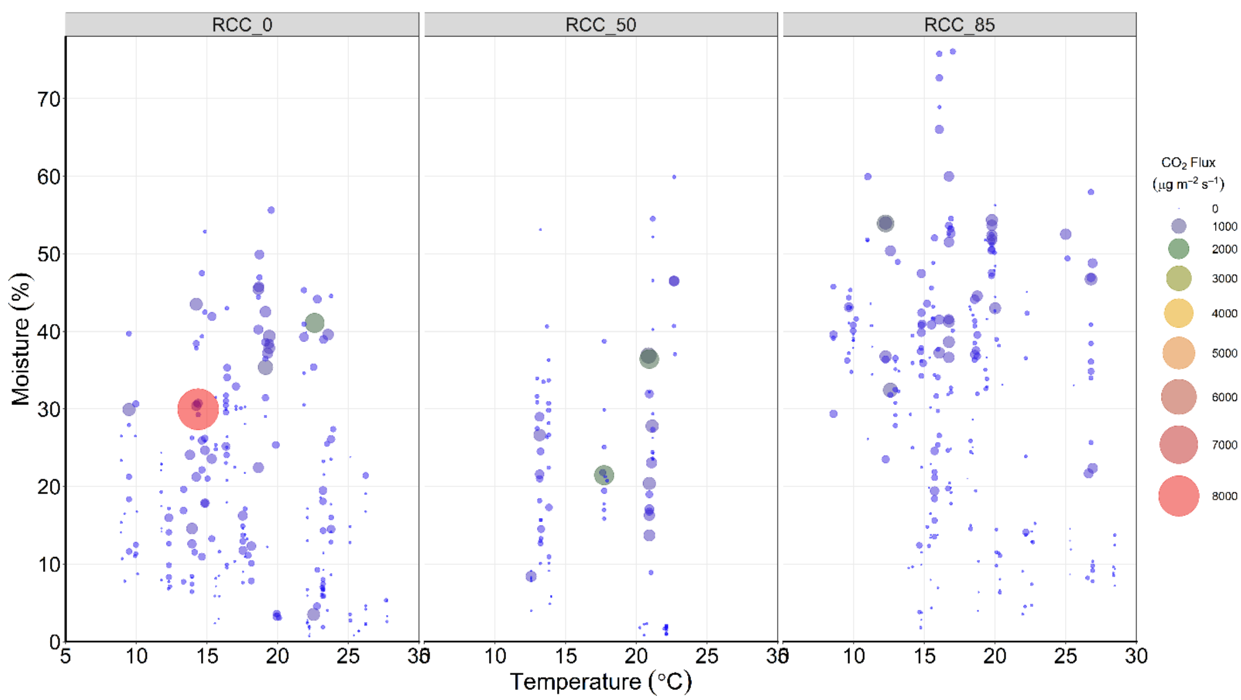

Fig. E14. Scatterplot of CO_2 emissions relative to temporally and spatially corresponding manure moisture content and ambient air temperature values.

Table E10. Summary statistics for manure moisture content (%) and ambient air temperature (°C) with respect to the different pen floor treatments

Statistic	**Pen Floor Surface Treatment**		
	Clay	**Mixed**	**RCC**
Manure Moisture Content (%)			
Median:	16.0[a]	17.1[a]	32.0[b]
Mean:	18.7	18.9	29.2
Maximum:	61.9	59.9	76.1
Minimum:	0.5	0.4	1.8
Ambient Air Temperature (°C)			
Median:	17.7[a]	17.7[b]	16.9[a,b]
Mean:	18.4	17.4	17.7
Maximum:	27.7	22.7	28.5
Minimum:	8.9	12.6	8.6

Median values with superscripts of the same letter were not significantly different ($\alpha = 0.05$)

APPENDIX F: The Economics of Rolled compacted concrete (RCC) Feedlot Flooring

F.1 Abstract

We use a multi-year benefit-cost framework to analyze the on-farm economic feasibility of retrofitting feedlot pens with Rolled Compacted Concrete Technology (RCC) in the context of a comprehensive empirical feedlot study in Southern Alberta. Given the assumptions of our framework, the net present value (NPV) per pen is positive and just under $55,000 per pen over a 20-year period. The payback time for the base case scenario ranges between six years (three per cent discount rate) and seven years (five and seven per cent discount rate). Payoffs to this investment under the current assumptions are high: The internal rate of return (IRR) of the investment is approximately 15 per cent per year. The calculated NPV values translate to an average NPV of $5.60 per animal ($7.45 per head and 4.15 per head at five and seven per cent discount rates, respectively). The economic performance of RCC technology is robust and competitive, but sensitive to changes in single variables. Moreover, it may not be generalizable as the economic results must be placed in the context of the management practices of the specific feedlot operation. If costs associated with clay pen maintenance (such as manure hauling or clay replacement quantities and unit costs) drop RCC technology tends to be less competitive. Industry-wide net benefits of RCC technology may range around $65,078 per year for every one per cent of Alberta's feedlot herd (equivalent to approximately 12,000 head, 2017) equipped with RCC technology. Individual feedlot owners need to be advised to re-calculate the expected costs and benefits of RCC technology for each individual operation.

F.2 Economic Analytical Framework

F.2.1 Overview

Replacing clay feedlot flooring with Roller Compacted Concrete (RCC) flooring presumably reduces mud in feedlot pens, thus improving animal health and production efficiency and, hence, lowering production costs. In addition, researchers hypothesize that improved RCC flooring leads to positive environmental effects, and increased consumer and farm worker satisfaction who may value improved animal welfare.

We use a benefit-cost-framework to analyze the economics of this investment decision, and to answer most salient questions like: "Is amending pen floors with RCC a rational economic choice ("cost effective")?"; "Which factors drive that decision?" and "How long will it take to pay for it?"

Benefit-cost analysis is designed (i) to take into account the market and non-market benefits and costs of an investment ("project"); and (ii) to isolate a single decision metric even if costs and benefits occur in different time periods by way of "Net Present Value" (NPV). The costs and benefits associated with pen floor investment are a mix of private and/ or public[1] costs and benefits which occur both on-farm and off-farm and which are categorized in Figure 1.

[1] While private goods are traded in markets, public goods typically suffer from market failures. However, the concept of "private" and "public" is increasingly fluid as, over time, markets establish for previously not tradeable goods such as for example, air and water pollution (Carbon market).

Figure 1: Expected Benefit and Cost Components for Improved Feedlot Flooring

	On-farm		Off-farm	
	Private (market)	Public (non-market)	Private (market)	Public (non-market)
Economic Benefits	• Improved meat production efficiency and quality (reduction in cost of gain ($/lb))	• Reduction of manure leakage (kg or g /m²)	• Additional net production effects in forward or backward linked sectors (clay; meat processing; etc.)	• Reduction of environmental pollutants (GHG emissions; water; etc)
	• Reduction of clay replacement costs in RCC pens; • Reduced manure hauling costs in RCC pens	• Increased job satisfaction of farm workers due to improved/ perceived animal welfare. • Ability to clean pens year-round[2]		• Increased consumer satisfaction from improved/ perceived animal health
Economic Costs	• RCC flooring installation • RCC maintenance costs			• Increased surface run-off into the environment (kg or g /m²)

Source: Own

However, despite the potentially broad framework of this approach, data limitations and methodological difficulties[3] make the inclusion of all public costs and benefits difficult. Therefore, we reduce our approach for the purpose of our study along the following considerations:

- As mentioned, we model the change from old to new technology as the retro-fitting of existing, conventional clay flooring for cattle feedlots with a Rolled Compacted Concrete (RCC) surface. The analysis excludes the comparison of new construction with the two floor types, which may involve building code regulations and additional cost items.
- We limit our economic analysis to private, monetary costs and benefits, which occur on-farm. Resulting net benefits per year are discounted to the base period and aggregated over the investment period. This net present value (NPV) of the investment is the central decision metric.
- On-farm benefits are cost savings[4] (either per year or in periodic intervals) when switching from old (clay) to new (RCC) flooring technology, i.e. the production cost differential across pen types (clay versus RCC). These items include:
  - cost differential of Cost of Gain (CoG) per pound ($/lb), between clay and RCC;
  - savings in clay replacement in clay pens ($/pen); and
  - cost savings in hauling manure-clay mixtures ($/pen).

2 Western Producer: https://www.producer.com/2017/10/producers-pleased-with-compacted-concrete-floors/

3 A particular difficulty is the transfer of welfare measures between studies and different contexts.

4 Cost reductions refer to a normalized live weight gain of 556 pounds per head. We chose this approach to eliminate differences in productivity and or sales price changes (revenue), as revenue is substantially driven by marketing factors (price hedging, marketing channels, etc.).

- On-farm costs for the RCC technology include floor installations and pen maintenance, both in dollars per square footage or dollars per pen ($/pen).
- Off-farm effects such as non-market (or public) costs and benefits will be accounted for in a qualitative way. Public goods comprise items such as environmental improvements from changes in water quality or greenhouse gas (GHG) emissions, run-off and nutrient loads, and extend to preferences for animal welfare by feedlot workers or consumers. While some of these potential effects are quantified in this study (e.g.: GHGs; run-off), the valuation of these effects may be methodologically challenging as non-market values are difficult to establish, and the transferability of values from other studies is typically limited. Moreover, off-farm effects in forward or backward linked sectors such as the clay industry, are not treated in this analysis.

F.2.2 Economic Metric: Net Present Value

The central decision metric of our on-farm benefit-cost framework is the discounted sum of net benefits (Net Present Value, NPV) of a retro-fitted RCC pen for a standardized pen size and a given production output (weight gain) over the assumed investment period. For our NPV calculations, we assume a lifespan for RCC flooring (investment period) of 20 years and we use a discount rate of five per cent per year (as well as three per cent and seven per cent) when aggregating net benefits over time.

F.2.3 Specifications and Assumptions for NPV Calculations

We use empirical data and industry information along with supplementary assumptions to specify benefits and costs for our economic analysis. Empirical data was gathered through a live feedlot study conducted in Southern Alberta. A total of 42 paired cattle lots with approximately 260 head in each lot were monitored between 2016 and 2018 in a (randomized) matched pairs design study for major production, animal health, environmental, and economic key variables. The economic comparison of RCC and Clay pen performance is based on 12 paired cattle lots (heifers) in RCC and Clay pens. This allows a direct comparison between the two floor types. Mixed (clay/RCC flooring) pens (a total of nine pairs, 18 lots) as well as two lots of steers were omitted from the economic analysis. A multi-variate OLS regression analyses suggest that RCC feedlot flooring significantly increases the average daily gain (ADG) of cattle and, in turn, an increase in ADG significantly lowers cost of gain.[5]

The following Table 1 and Table 2 summarize empirical and assumed or calculated values, respectively, for the variables of our model as explained above.

[5] Model 1 analyzes drivers in variation of Average Daily Gain (ADG) by modelling ADG (dependent variable) as a function of square footage, floor type, maximum and minimum air temperature and precipitation. Floor type, amongst others, is a significant driver of ADG. Model 2 analyzes Cost of gain as a function of average daily gain, drug expenditures and feed costs. We find that CoG per pound is significantly influenced by average daily gain, confirming the prediction that more efficient meat conversion lowers production costs per pound.

Table 1: Basic empirical measurements for NPV Model (Base)

Variable		Values	Information Source
Pen size Clay,	(sqft)	35,303	Empirical average for clay pens
	(m2)	3,280	Converted
ADG (lb/day/head) differential		0.0857	Empirical differential btw RCC and Clay pens
DoF (days), clay		175	Empirical average for clay pens
Animals per lot (hd/pen), clay		260	Empirical average for clay pens
Pounds gained per head (lb/hd), 175 DoF		555.5	Empirical average for clay pens
CoG per pound ($/lb) differential		$0.0192	Empirical differential btw RCC and Clay pens
Manure Differential (tonne/head)		0.560	Empirical differential btw RCC and Clay pens

Source: Empirical feedlot study (2019).

Table 2: Assumed or calculated Parameters for NPV Model (Base)

Variable		Values	Information Source
RCC Cost savings per head ($/lb)		$10.66	Calculated for weight gain 555.5 lb/head
RCC coverage, 70% (sqft)		24,712	Industry information (excl. apron; water pad; rest area)
"	(m2)	2,296	Sqft converted to m2
Occupancy		90%	Industry information
Turns per year (175 DoF, 90% occupancy)		1.88	Calculated, based on occupancy
Animals per pen per year		488.79	Calculated, based on head per lot and occupancy
Pounds gained per pen (lb/pen)		271,528	Calculated, based on animals/ pen and turns
Unit cost RCC Installation ($/sqft)		2	Industry information, Western Producer
Unit cost pen cleaning/ manure management ($/m3)		7.50	Industry information
RCC maintenance per year (%)		1	Industry information
Clay replacement depth (m), every three years		0.28	Industry information, based on 5 cm p.a.
Unit cost Clay replacement ($/m3)		6	Industry information
Investment period (yrs)		20	Standard assumption
Discount rate (% p.a.)		5	Standard assumption; also 3% and 7% p.a.

Source: Industry information and own calculations.

We standardize pen size using the empirical clay pen information. Based on Table 1 an average clay pen has the following specifications:

- Size: 35,303 square feet (3,280 m2)
- 260 animals per lot

In addition, we assume an occupancy rate of 90 per cent per pen which implies 1.88 turns of cattle per pen per year.[6] This results in 489 head per pen and 271,528 pounds gained per pen and year, respectively.

[6] 365 days * 90% / 175 DoF = 1.88 turns per year.

We use these specifications to calculated net present values for three discounts rates (three, five and seven per cent per year), as well as "what if" scenarios for salient variables of the analysis.

F.2.4 Cost and Benefit Components

F.2.4.1 Expected Benefits from RCC Flooring Technology

Savings in Cost of Gain ($/lb) on RCC flooring

Our empirical data suggests a cost of gain on clay of $0.9492 per pound and the cost of gain on RCC flooring of $0.9300 per pound. This is a differential in average cost of gain (CoG), measured in dollars per pound ($/lb), of approximately $0.0192/lb (1.3 per cent) between clay and RCC flooring.[7]
We need to convert cost of gain per pound ($/lb) into a standardized cost of gain per head ($/hd) as investment calculations are based on costs per square footage. We equalize our measured cost of gain per pound to a standard production of 175 DoF and a weight gain of 556 lb/hd (clay pens).The cost difference of $0.0192 per pound (excluding costs for manure management which are calculated separately) translate into cost savings (benefits) of $10.66 per head based for 556 pounds gained and 175 DoF per head (556lb/hd * $0.0192/lb).[8]

Savings in clay replacement costs ($/m3) for RCC flooring

The absence of clay replacement costs is another benefit of RCC flooring compared to clay flooring. While different management practices exist, industry information[9] seems to suggest that approximately 5 cm of clay is removed from clay pens at cleanout. At the assumed 90 per cent occupancy rate (i.e. 1.88 turns per year) this removal translates to approximately 28 cm[10] of clay over a three year period. We value reduced clay replacement at six dollars per one cubic meter replaced ($6/m3).

Savings on manure management costs ($/MT) for RCC flooring

The amount of clay mixed into the cattle manure impacts manure management costs (scraping; loading; hauling; spreading) as more material is being removed from clay pens than from RCC pens. Data suggests a manure-clay mixture differential between pen types of approximately 0.560 metric tonnes per head.[11] This estimate corresponds with calculations of clay removal of approximately 5 cm during each clean out.[12] Manure hauling is valued at $7.50 per metric tonne (scraped; loaded; hauled). We analyze this cost component separately from cost of gain (above) to allow for sensitivity analysis of the economic outcome to changes in manure hauling.

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7 Cost reductions are induced by improved average daily gain (ADG). According to our feedlot study data the mean for ADG is 3.1771 lb/day per heard for *"clay lots"* versus 3.2628 lb/day per head for *"RCC lots", resulting in a difference of* 0.0857 pounds per day (2.7%).

8 Alternatively, RCC technology reaches the target weight of 556 pounds in 170 days (= 556 pounds/3,2658 lb/day). However, as a reduction in DoF affects the revenue stream per pen we need to equalize costs.

9 Based on discussions with feedlot owner.

10 5 cm/turn * 1.88 turns / year * 3 years = 28.2 cm removal. Note that occupancy rate affects clay removal.

11 Estimates provided by Dr. Atta Atia, Alberta Agriculture and Forestry, Livestock Air Quality Specialist Land Use Unit. The empirical findings suggest manure-clay mixtures of 8.21 kg per head day for clay pens and 4.93 kg per head day for RCC pens (see also Characteristics of Manure Harvested from Beef Cattle Feedlots) and, accordingly, 1.44 metric tonnes per head for clay and 0.86 metric tonnes per head over 175 days on feed.

12 Clay loss during clean out: (0.05 cm * 2,296m^2 =) 114.8m^3 (clay) * 1.33mt/m^3 (specific weight of clay) / 260 head/pen = **0.587 mt/head**.

F.2.4.2 Expected Costs of RCC Flooring Technology

Investment and maintenance costs for RCC flooring
Investment costs for the retro-fitting of RCC flooring are assumed at two dollars per square foot ($2/sqft)[13]. We further assume a standardized pen of approximately 35,300 sqft, with a RCC replacement area of approximately 70 per cent or 24,700 sqft excluding apron, water pad and rest area. Total investment costs per pen are calculated at $49,400 per pen.
While annual RCC maintenance costs have not been reported during the time of the experiment, we choose to include these costs at one per cent of investment value per year[14].

F.3 Economic Impacts of RCC Flooring

F3.1 Net Benefits of RCC Flooring (Base Scenario)

Under the given assumptions and the specific management regime at the study feedlot we calculate the following benefits and costs from RCC flooring per pen:

Benefits:

- Savings on Cost of Gain (annually):
  $10.66/head * 260 head per lot * 1.88 lots per year = $ 5,210.86/ pen/ year
- Savings on pen cleaning/ manure hauling (annually):
  0.574 mt/ head / year * 489 head/ pen/ year * $7.50/mt = $ 2,104.71/ pen/ year
- Savings on clay replacement (every three years):
  2,296 m^2 (area replaced) *0.28m (Clay loss, three years) = 645 m^3,
  priced @ $6/ m^3 = $ 3,881.99/ pen/ three years

Costs:

- Investments Costs (once): = $ 49,424 per pen[15]
- RCC Maintenance Costs (annually) = $ 494 per pen[16]

F3.2 Net Present Values (Base Scenario)

The following Table 3 reports on the net present values for three different discount rates, broken down into the main metrics of interest (total NPV per pen; NPV per pen and year; NPV per head; NPV per pound gained, see annex for set-up of the model).
At a standard discount rate of five per cent[17], our base case scenario yields a net present value benefit of $54,700 per standard feedlot pen over 20 years. This is equivalent to about $2,700 per

[13] Industry information; Western Producer https://www.producer.com/2016/02/new-flooring-could-end-muddy-feedlot-pens/; https://www.producer.com/2017/10/producers-pleased-with-compacted-concrete-floors/
[14] Information provided by feedlot owner.
[15] 24,712 sqfr/ pen * $2/ sqft = $ 49,424/ pen
[16] $ 49,424 * 1%/ year = $ 494/ pen/ year
[17] This is in sync with Bank of Canada rates for conventional five-year mortgage rates.

(standardized) pen per year, or $5.60 per head per year, or just over one cent per pound gained. A lower discount rate, i.e. three per cent, makes investments more favorable and increases the net present values of the investment. Conversely, if we assume a higher opportunity cost of money (higher time preference/ discount rate), all net present values decrease. See annexure for NPV calculations. Under the given assumptions, the internal rate of return (IRR) of the RCC technology is approximately 15 per cent.[18]

Table 3: Net Present Values, Base Scenario (3%, 5% and 7% discount rates)

DISCOUNT RATE	Total NPV per pen (20 YRS)	per pen/year	per head	per sqft/ year	per lb gained
3%	$72,872.53	$3,643.63	$7.45	$0.15	$0.0134
5%	$54,724.07	$2,736.20	$5.60	$0.11	$0.0101
7%	$40,540.38	$2,027.02	$4.15	$0.08	$0.0075

Source: Own calculations

F3.3 Pay-off Period

The pay-off period of RCC flooring under the base case specifications for the investment in RCC technology is between six and seven years at three per cent and five per cent or seven per cent discount rate, respectively.

F3.4 Analysis of Worse and Better Case Scenarios

We formulate two corner scenarios, *Worse Case* and *Better Case* (*Table 4* and

Table 5), implying that salient variables are simultaneously less favorable and more favorable, respectively. The interpretation of signs depends on our initial assumptions regarding expected costs and benefits. For example: Since RCC pen floors presumably save costs on manure hauling, an increase in the assumed costs of manure hauling would result in higher savings per pen, hence a more favorable outcome. Similar reasoning applies to unit cost for clay replacement and required excavation depth, or the amount of manure reduction per head on RCC flooring.

Table 4: Worse, Base and Better Case Scenarios (percentage changes)

	Worse Case	Base Scenario	Better Case
Cost savings from CoG per head ($/hd)	-50%	$10.66	+50%
Unit cost manure management ($/tonne)	-50%	$7.50	+50%
Unit cost Clay replacement ($/m3)	-25%	$6	+25%
Reduction of manure (tonne/hd)	-50%	0.574	+50%
Clay replacement excavation depth (m)	-50%	0.28	+50%
Maintenance Costs (%/year)	3%	1%	0.5%
Unit cost RCC Installation ($/sqft)	$3	$20	$1

18 The internal rate of return of an investment is the return on each dollar invested when the investment breaks even (NPV=zero). It can be used to assess an investment options relative to alternatives.

Table 5: Worse, Base and Better Case Scenarios

	Worse Case	Base Scenario	Better Case
Cost savings from CoG per head ($/hd)	$5.33	$10.66	$15.99
Unit cost manure management ($/tonne)	$3.75	$7.50	$11.25
Unit cost Clay replacement ($/m3)	$4.50	$6	$7.50
Reduction of manure (tonne/hd)	0.287	0.574	0.861
Clay replacement excavation depth (m)	0.141	0.28	0.423
Maintenance Costs (%/year)	3%	1%	0.5%
Unit cost RCC Installation ($/sqft)	$3	$2	$1

Source: Own

Table 6 (below) reports NPV values in dollars per head for three discount rates and for three scenarios. The table shows the benchmark of $5.50 per head of the base scenario and a five per cent discount rate. This value increases for the *Better Case* to $13.39 per head, and decreases for the *Worse Case* to negative $4.21 per head, in fact, rendering RCC technology economically infeasible for any of the discount rates.

Table 6: NPV per head ($/head) for three scenarios and three discount rates

Discount Rate	Worse Case	Base Scenario	Better Case
3 %	-$3.64	$7.45	$16.20
5 %	-$4.21	$5.60	$13.39
7 %	-$4.66	$4.15	$11.20

Source: Own calculations

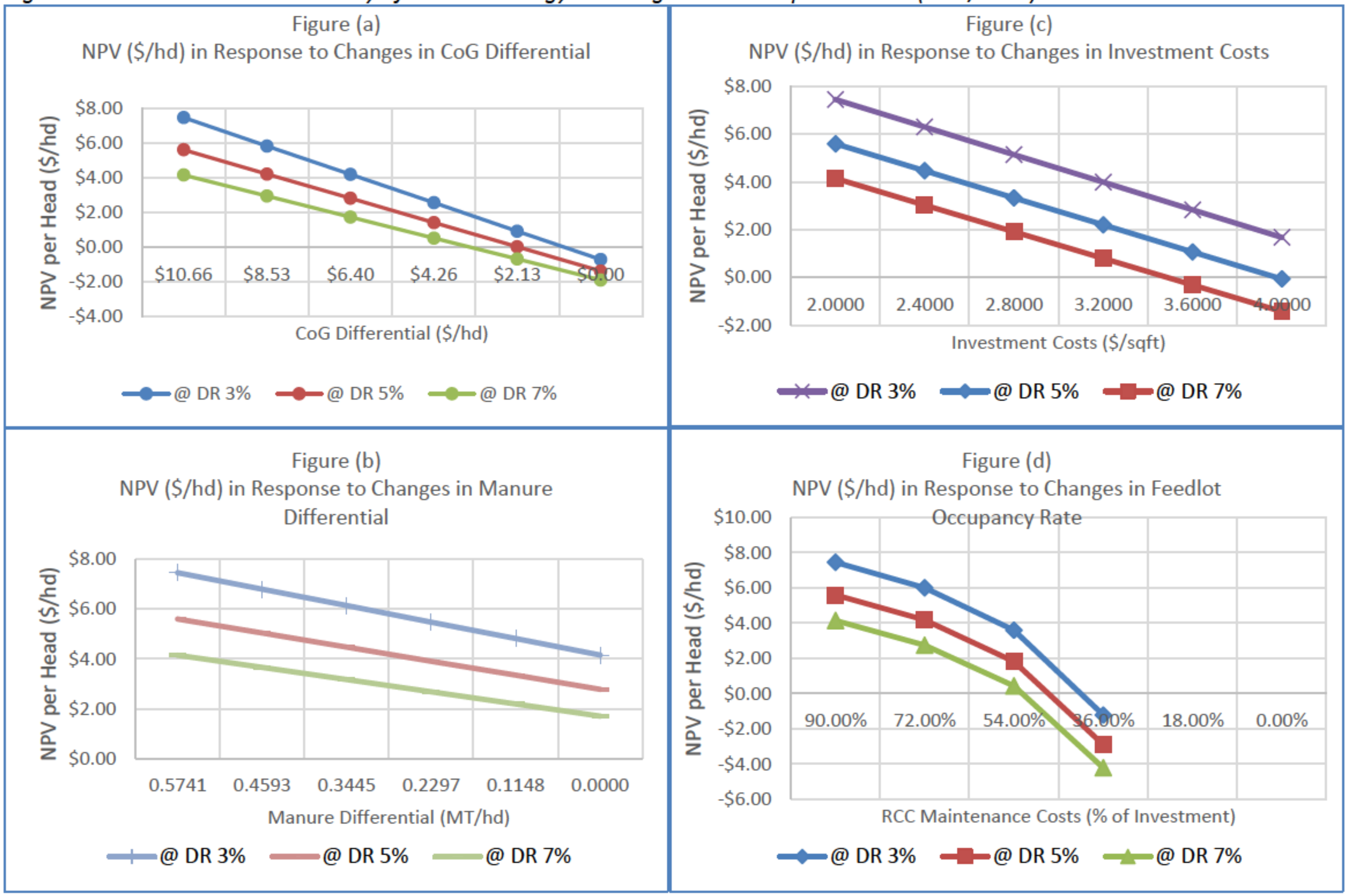
F3.5 Sensitivity Analysis

Subsequently, we will analyze the robustness of the base model to changes in a single variable, such as CoG, investment costs, depth of clay replacement, manure hauling etc. These *"what if?"* scenarios establish cornerstones in the assessment of the economic feasibility of the investment and aid with decision making. Figure 2 (a) to (d), overleaf, show the results.

F3.5.1 Cost of Gain ($/head)

Let us assume that the differential in Cost of Gain attributable to RCC technology drops in 20 per cent increments toward zero; in other words, RCC would not – ceteris paribus – noticeably reduce cost of gain per head (or per pound). As the Figure 2 (a) shows, the investment becomes economically infeasible when producers, all other assumptions being equal, achieve less than $2.13/head in costs savings from RCC technology (for a discount rate of five per cent).

Figure 2: Economic sensibility of RCC technology to changes in salient parameters (NPV/head)



Source: Own calculations

F3.5.2 Manure Management Cost (mt/head)

Next, we assume that the manure reduction of RCC is less favorable than our initial base case. Again, we reduce the manure differential between the two technologies in 20 per cent increments towards zero. The graph below shows that RCC investment is less sensitive to changes in cost savings from manure management. Even if there is no difference in the amount of manure to be processed between technologies, i.e. 0 mt per head, the investment remains economically feasible, albeit at a lower return of $2.78 per head (for a discount rate of five per cent).

F3.5.3 Investment Costs ($/sqft)

Thirdly, we analyze the economic sensitivity of the investment in response to incremental increases in investment costs. We incrementally double investment costs from the initial $2 per sqft assumption to $4 per sqft and analyze how the economic feasibility investment changes. *Figure 2* shows that doubling the investment cost from $2 per sqft to $4 per sqft at a 5 per cent discount rate erodes NPV to zero.

F3.5.4 Occupancy Rate

We recognize that our initial assumption of a 90 per cent occupancy rate is reflective of the management structure of the feedlot operation and may not hold across all feedlots. Comparable to the other variations, we reduce occupancy in 20 per cent intervals from 90 per cent to 72 per cent, 54 per cent and 36 per cent, respectively. Figure 2 above shows the response of NPV per head accordingly. Even at a rather low occupancy rate of 72 per cent (at five per cent discount rate) the investment in RCC flooring remains economically feasible.

F3.6 Industry-wide Impacts

The assessment of industry-wide impacts is challenging as our results are – strictly speaking – site specific to feedlot where the experiment was carried out. Extrapolating industry-wide bears the criticism that, even if our study feedlot were a fair representative of the average feedlot of the industry, inferences for operations along the production frontier are difficult to make as our study does not uncover the input output relationships at different efficiency levels. The impacts as calculated below, therefore, are to be read with caution.

As a proxy for industry effects, we use the Canfax feedlot demographics[19] and apply the findings of this study for average cost savings per head from RCC across Alberta's feedlot herd. Table 7 below summarizes demographic information for feedlots in Alberta. Using columns (2) and (3), we calculate the number of finished animals per year in each category (column (4)) at a total sum of 1.188 million animals. Moreover, we re-calculate the specific cost savings per head (column 5), using the model of the previous section and applying the stated occupancy rate for

[19] Canfax Annual Report, 2017, p 25 and 26.

each category (column (3)). Using column (6) allows us to calculate an approximated weighted average cost saving per head of $5.48 (sum of column (7)) across the industry. [20]

Table 7: Study-specific cost savings from RCC technology, applied to Alberta's Feedlot Demographics

Bunk Capacity (1)	Total Capacity (2)	Fill rate (2018)* (3)	animals per year (4)	Average Cost Saving ($/head) Cost / head ** (5)	% of herd (6)	weighted*** (7)
1,000-5,000	164,000	71%	116,440	**$4.08**	9.80%	$0.40
5,000-10,000	219,600	95%	208,620	**$5.90**	17.55%	$1.04
10,001-15,000	143,400	92%	131,928	**$5.72**	11.10%	$0.64
15,001-20,000	213,500	89%	190,015	**$5.53**	15.99%	$0.88
> 20,000	608,300	89%	541,387	**$5.53**	45.56%	$2.52
Industry	**1,348,800**	**88%**	**1,188,390**			**$5.48**

Source: Canfax annual report, 2017, p. 25 and 26; own calculations

Notes: * Canfax reports a fill rate of 89% for a capacity of > 15,000 animals. **Average cost savings for each category, column (1), are calculated using NPV model from the previous section at the specific occupancy rates (column (3)); ***We multiply columns (5) and (6) row by row to construct the industry-wide average cost savings.

New technologies are typically adopted in stages, first by industry pioneers, then by a majority of the industry and then by late bloomers. Since we do not know the adoption behavior for RCC technology, it seems reasonable to calculate industry benefits for each one per cent of adoption.

Table 8: Annual Industry Benefits ($/year) at different adoption rates

	100%	80%	60%	40%	20%	1%
1,000-5,000	$475,241	$380,193	$285,145	$190,097	$95,048	$4,752
5,000-10,000	$1,230,050	$984,040	$738,030	$492,020	$246,010	$12,300
10,001-15,000	$754,769	$603,815	$452,861	$301,908	$150,954	$7,548
15,001-20,000	$1,051,582	$841,266	$630,949	$420,633	$210,316	$10,516
> 20,000	$2,996,147	$2,396,917	$1,797,688	$1,198,459	$599,229	$29,961
Total	**$6,507,788.31**	**$5,206,230.65**	**$3,904,672.98**	**$2,603,115.32**	**$1,301,557.66**	**$65,077.88**

Source: Canfax annual report, 2017, p. 25 and 26; own calculations

Table 8 shows the total cost savings for a choice of different adoption rates. For example, if 40 per cent of cattle are kept in feedlots with RCC flooring, our study results suggest that annual cost savings amount to approximately $2.6 million. For every one per cent (11,894) of animals on RCC flooring we calculate a total annual cost saving of $65,078 per year for the industry[21].

20 With this method, it is not surprising that at 88% occupancy (industry average) the calculated average cost savings per head ($5.48/head) is very close to our site specific findings of $5.60/ head.

21 1.188 million head x 1% x $5.48/head = $65,078 per year.

F4 Concluding Remarks

Our analysis suggests that the economic performance of RCC technology is competitive and robust, albeit sensitive to cumulative changes in key variables that influence RCC performance. Naturally, operations with high clay replacement costs or high manure management costs can be expected to benefit from an RCC retrofitting. RCC technology remains competitive – all else equal – as long as the differential in cost of gain between clay and RCC flooring exceeds approximately $2.13 per head (0.36 cents per pound) and investment costs per square foot remain below $4 per square foot. Based on the on-farm results of our study we calculate industry-wide benefits of RCC technology at approximately $65,078 per year for every one per cent of Alberta's feedlot herd (equivalent to approximately 12,000 head, 2017) equipped with RCC technology. For example, am RCC retrofitting for 20 per cent of Alberta's feedlot population would generate industry benefits of approximately $1.3 million per year. However, the economic performance of RCC flooring as described in this study must be understood in the context of the specific management practices of the feedlot operation which hosted the experiment. A generalization of the findings to the wider feedlot sector in Alberta requires caution, and will depend on whether or not these management practices are considered representative of Alberta feedlots. For example, any operation's average daily weight gain (ADG) – and with it technology-induced differences in corresponding cost of gain (COG) – differs according to its overall efficiency, i.e. its location on the production frontier. In other words, we cannot assume that our ADG improvements from RCC technology as reported in our study automatically hold industry wide, because we have not uncovered the underlying production functions and the impacts of technology along the input/output relationship. Results, therefore, are an indication of direction rather than of magnitude, and enterprises must be advised to calculate potential impacts of retrofitting their feedlot floors at their individual operational level. The economic analysis focusses on on-farm economics of RCC technology. In addition, a benefit-cost framework is capable of capturing public off-farm benefits such as potential reductions in Greenhouse gas (GHG) emissions and water pollution or animal welfare improvements. If these benefits are measurable and if markets for them exist, feedlot owners might capitalize these values in form of market revenues, and incorporate them into their annual benefit stream.

Annex to Appendix F

Table F-A1: Net Present Value Calculations (Base Case)

			year 0	year 1	year 2	year 3	year 4	year 5	...	year 18	year 19
EXPECTED NET BENEFITS (RCC technology) (1+2) - (3+4)			**-$42,108.53**	**$6,821.34**	**$6,821.34**	**$10,703.33**	**$6,821.34**	**$6,821.34**		**$10,703.33**	**$6,821.34**
NET PRESENT VALUE											
per pen (20yrs)	**NPV = 0**	**discount rate**									
$72,872.53	**6.00**	3.00%	**-$42,108.53**	**$6,622.66**	**$6,429.76**	**$9,795.06**	**$6,060.67**	**$5,884.14**		**$6,287.08**	**$3,890.11**
$54,724.07	**7.00**	5.00%	**-$42,108.53**	**$6,496.51**	**$6,187.15**	**$9,245.94**	**$5,611.93**	**$5,344.70**		**$4,447.45**	**$2,699.43**
$40,540.38	**7.00**	7.00%	**-$42,108.53**	**$6,375.08**	**$5,958.02**	**$8,737.10**	**$5,203.96**	**$4,863.52**		**$3,166.73**	**$1,886.16**
EXPECTED BENEFITS (due to new technology)											
Total (1, 2, 3)			**$7,315.58**	**$7,315.58**	**$7,315.58**	**$11,197.57**	**$7,315.58**	**$7,315.58**		**$11,197.57**	**$7,315.58**
1. ADG efficiency											
Improved CoG (annually)	*$/pen*	$5,210.86	$5,210.86	$5,210.86	$5,210.86	$5,210 86	$5,210.86	$5,210.86		$5,210.86	$5,210.86
2. Manure Hauling											
Reduced maure hauling (annually)	*$/pen*	$2,104.71	$2,104.71	$2,104.71	$2,104.71	$2,104.71	$2,104.71	$2,104.71		$2,104.71	$2,104.71
3. Pen Maintenance (estimated)											
Omittable clay replacement ***(every 3rd year)***	*$/pen*	$3,881.99	$0 00	$0.00	$0.00	$3,881.99	$0.00	$0.00		$3,881.99	$0.00
$1,294.00	n excav., every three years)										
EXPECTED COSTS (due to new technology)											
Total (4, 5)			**-$49,424.11**	**-$494.24**	**-$494.24**	**-$494.24**	**-$494.24**	**-$494.24**		**-$494.24**	**-$494.24**
3. RCC Pen Flooring Installation											
Cost of RCC Flooring	*$/pen*	**$49,424.11**	**$49,424.11**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**		**$0.00**	**$0.00**
4. RCC Pen Flooring Maintenance											
RCC Floor Repairs, per pen	*%*	1%	**$0.00**	**$494.24**	**$494.24**	**$494.24**	**$494.24**	**$494.24**		**$494.24**	**$494.24**

Table F-A2: Net Present Value - Results (Base Case)

NET PRESENT VALUES		BASE SCENARIO			
DISCOUNT RATE	Total NPV per pen (20 YRS)	per pen/year	per head	per sqft RCC/ year	per lb gained
3.00%	$72,872.53	$3,643.63	$7.45	$0.15	$0.0134
5.00%	$54,724.07	$2,736.20	$5.60	$0.11	$0.0101
7.00%	$40,540.38	$2,027.02	$4.15	$0.08	$0.0075

APPENDIX G; PROJECT EXTENSION AND COMMUNICATION PLAN

Purpose

The purpose of this extension plan is to disseminate, extend and promote the findings and outcomes of this research project to end-users. The target end users of the study results include feedlot operators, livestock industry groups, and government policy makers. Extension activities outlined by this plan will provide the feedlot operators with detailed, credible information to enable them to confidently make decisions regarding the risks, benefits and costs associated with adopting RCC pen floors in feedlot cattle production practices. The extension plan will also encourage producers to either adopt this practice because it has a positive net benefit (i.e., the research project indicates it is effective, practical, and economically feasible, with a limited number of tradeoffs) or not to adopt the practice, because it has a negative net benefit. The plan is also intended to provide industry and government policy makers with credible information to facilitate decision making.

Goals

The main goals of this extension plan are to:

- Enhance feedlots operators' knowledge and understanding of the costs and benefits associated with re-surfacing feedlots pens with RCC;
- Provide recommendations, if any, on management practices that must be considered upon installing RCC in feedlot pens;
- Promote the use of RCC if it has been proven to be effective and economically feasible.

Objectives.

- To widely communicate and disseminate project research results to feedlots operators', industry groups and researchers.
- To use effective, diversified and non-traditional extension tools to implement the plan.

Partnerships

- Alberta Beef Producers
- Alberta Cattle Feeders' Association
- The Canadian Cattlemen's Association
- RCC suppliers and custom applicators

Target Audience

- Feedlot operators
- Industry and livestock commodity groups
- Academia and scientific community
- Government policy makers

Key Messages

The following key messages will be tailored to each target audience based on the level of their needs and interest in the research results.

- Impact of RCC on the animal health and welfare.
- Economic feasibility and practicality of installing RCC
- Environmental costs and benefits.

Strategies and Tools

Strategy	Tools	Timeline	Updates	Target Audience	Responsibility	Budget
Popular press articles	Publish -articles in the following farm press publications and newsletters: AF Agri-News The Western Producer Magazine Alberta Beef Magazine Farming for Tomorrow Magazine	December 2019	• Three articles published to date about the project and preliminary findings.	• Feedlot Operators	Atta to coordinate A technical writer and guidance from the steering team	$ 2500
Scientific presentations	Present (oral or poster) project findings at the following events: Manure Management Update (Lethbridge)	Jan 2019 March 2019	Done - Preliminary results presented. Done - Preliminary	Producers, Industry, livestock commodity groups Producers, Industry,	Shared responsibility between Project Steering Team	Travel expenses

Strategy	Tools	Timeline	Updates	Target Audience	Responsibility	Budget
	Alberta Cattle Feeders' Association AGM Waste to Worth Conference (Minneapolis) **Canadian Society of Animal Science (CSAS) Annual Meeting (???)**	April 2019 July 2019	results presented.	livestock commodity groups Scientific Community Scientific Community		
Scientific publication in peer reviewed journals	Publish scientific articles in the following peer reviewed journals	2019 - 2020		Scientific Community		
	Canadian Journal of Animal Sciences (Animal Health and Welfare)				Steve	
	Agriculture, Ecosystems and Environment (Ammonia and GHG)				Ike	

Strategy	Tools	Timeline	Updates	Target Audience	Responsibility	Budget
	Journal of Environmental Quality (Runoff)				Greg	
	Transactions of the ASABE (RCC)				Ike	
	Canadian Journal of *Agricultural Economics (Economics)*				Anne	
Social Media	Post targeted key messages from the project results in the following Social Media tools using AF social media account Twitter YouTube Facebook			Feedlot operators Industry, livestock commodity groups	Atta	in-kind
Professional Networking	Share the project results with scientific community through the following tools: ResearchGate Academia.edu			Scientific Community	Atta	in-kind

Strategy	Tools	Timeline	Updates	Target Audience	Responsibility	Budget
Webinars	Host a webinar upon project completion..			Scientific community	Shared responsibility between Project Steering Team	in-kind
Radio Interviews	AF's "Call of the Land"			Feedlot operators	Shared responsibility between Project Steering Team	in-kind
Display	Develop pop up display to be permanently stationed in Farm Stewardship Centre (FSC) in Lethbridge			Public	Atta + Laura T (AF)	$ 1000
Fact Sheets	Develop series of fact sheets				Shared responsibility between Project Steering Team	in-kind
Town hall meeting /Demo	Organize one site tour and/ or a town hall			Producers and industry people who may be interested in RCC	Steering team + Cody (AF)	$ 2000 for renting venue and hosting

Performance Measures

- Track information exchanged with industry/researchers and colleagues
  - Mail outs/information requests
  - Website hits

- Number of extension activities completed (e.g., number of workshops; number of scientific articles published in peer review journals, number of YouTube, Twitter and Facebook viewership, etc.)
- Number of livestock producers attending town hall /field demonstrations.
- Number of fact sheets distributed