Effects of cashew nut shell extract supplementation on enteric methane emissions and performance of natural feedlot heifers

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Abstract

Enteric methane (CH_4) from feedlot cattle is both a greenhouse gas and an energetic loss, diverting 2 to 12% of dietary gross energy (GE). Cashew processing produces large quantities of waste, some of which can be refined into cashew nut shell extract (CNSE), a phenolic-rich supplement containing anacardic acid. This study evaluated effects of CNSE supplementation on methane emissions, animal performance, feeding behavior, and carcass characteristics in finishing heifers. Sixty crossbred heifers (initial body weight = 515 ± 9 kg) were assigned to 1 of 4 treatments (n = 15/treatment): 0, 2.5, 5.0, or 7.5 g CNSE/heifer daily for 105 d. The CNSE (DynOmik, Adisseo, Alpharetta, GA) contained at least 25% anacardic acid. The finishing diet contained (DM basis) 23% corn silage, 20% distillers' grains, 55% corn, and 3% vitamin/mineral supplement. Intake and feeding behavior were recorded using an Insentec Roughage Intake Control (RIC) system (Hokofarm, Emmeloord, The Netherlands). Methane emissions were measured using an automated head chamber system (AHCS; GreenFeed; C-Lock Inc., Rapid City, SD). Relative to control, supplementation with 2.5 g/d CNSE increased dry matter intake (DMI) (12.64 vs. 11.86 kg/d), whereas supplementation of 5.0 (11.00 kg/d) and 7.5 g CNSE/d (10.72 kg/d) reduced DMI (cubic $P = 0.005$). Average daily gain (ADG) decreased linearly ($P = 0.02$) with lower ADG at the higher CNSE inclusion rates (1.31, 1.34, 1.17, and 1.17 kg/d for 0, 2.5, 5.0, and 7.5 g CNSE/d). Gain:feed ratio was not affected by treatment ($P \geq 0.33$). Heifers supplemented with 2.5 g CNSE/d had the greatest meal size (1.85 kg/meal), whereas meals per day increased with CNSE inclusion (linear $P = 0.03$) and eating rate decreased as CNSE inclusion increased (linear $P = 0.03$). Methane production (g/d) was not different among treatments ($P \geq 0.26$). Methane yield (g/kg DMI), CH_4 intensity (g/kg ADG), and Ym (% of gross energy) tended to exhibit a cubic response to CNSE supplementation, with the 2.5 g/d

treatment numerically lower than the 0. 5.0, and 7.5 g/d treatments (cubic $P = 0.095$, 0.092, and 0.077, respectively). Carcass characteristics, including fat thickness, ribeye area, hot carcass weight, marbling score, quality grade, and calculated yield grade were not affected by treatment ($P \geq 0.33$). Supplementation with CNSE altered feeding behavior and reduced growth performance at 5.0 and 7.5 g CNSE/d. Overall, CNSE supplementation did not reduce absolute CH_4 production, but the nonlinear responses in CH_4 yield, CH_4 intensity, and Ym suggest that a low dose of 2.5 g/d may provide modest methane mitigation without compromising growth performance.

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Chapter 1 - Literature Review

Introduction

Enhancing nutrient use efficiency in beef cattle is critical for both economic viability and reducing the environmental footprint of feedlot production. Feed represents the largest variable expense in finishing operations, and energy lost as enteric methane (CH_4) constitutes not only wasted feed but also the principal source of greenhouse gas emissions from beef cattle (Johnson and Johnson, 1995; Rotz et al., 2019). Methane has a 100-year global warming potential 27.2 times greater than that of carbon dioxide and a relatively short atmospheric lifetime; thus, reducing enteric CH_4 emissions represents an opportunity to mitigate near-term warming while also reducing dietary energy losses by the animal (IPCC, 2021).

Consumer demand for natural beef has led to the growth of programs that restrict the use of performance-enhancing technologies. Conventional feedlot production commonly utilizes anabolic implants, ionophores such as monensin, and β-agonists to improve average daily gain (ADG) and gain:feed (G:F), thereby reducing days on feed (Bergen and Bates, 1984; Cooprider et al., 2011). In contrast, natural programs prohibit these interventions, resulting in slower cattle growth, extended feeding periods, and greater total feed consumption to achieve equivalent slaughter weights (Smith et al., 2024; Cooprider et al., 2011). Because enteric CH_4 production increases as feed intake increases, differences in feed intake may be relevant when assessing methane emissions from natural beef production systems (Galyean and Hales, 2024).

Various CH_4 mitigation tools have been developed, though most were designed for conventional production systems. Ionophores modestly reduce CH_4 yield by shifting rumen fermentation toward propionate; however, their efficacy is limited, and they are not permitted in natural programs (Hristov et al., 2013). Potent biochemical inhibitors, such as

3-nitrooxypropanol and red seaweed (*Asparagopsis* spp.), can decrease CH_4 emissions by 30–90%, but their adoption is constrained by regulatory, supply, and consumer acceptance challenges (Hristov et al., 2015; Kinley et al., 2020; Ridoutt et al., 2022;). These limitations underscore the need for effective, scalable, and compatible mitigation strategies that align with natural production standards.

Cashew nut shell extract (CNSE) represents a promising plant-derived CH_4 mitigation strategy that also contributes to waste valorization. Cashew processing produces substantial quantities of shells as an agricultural byproduct. CNSE is commonly discarded, despite its content of cashew nut shell liquid (CNSL) rich in anacardic acids and related phenolics with selective antimicrobial activity against Gram-positive bacteria and methanogenic archaea (Watanabe et al., 2010; Shinkai et al., 2012). Both *in vitro* and *in vivo* studies suggest that appropriately processed CNSE can reduce ruminal CH_4 formation and shift fermentation toward propionate without significantly compromising digestibility, although outcomes vary depending on product composition and dosage (Shinkai et al., 2012; Mitsumori et al., 2014; Danielsson et al., 2014; Branco et al., 2015). However, most research has focused on dairy or forage-based systems, and evidence for efficacy in high-grain feedlot diets remains limited (Branco et al., 2015; Cuervo et al., 2025).

Conventional and Natural Feedlot Systems

In feedlot cattle, the primary difference between conventional and natural production systems lies in the use of technology rather than in the formulation of the basal diet. Conventional systems rely on anabolic implants, ionophores such as monensin, and β-agonists to improve growth rate and gain efficiency in grain-based diets (Bergen and Bates, 1984; Smith et al., 2024). Natural programs, in contrast, utilize similar corn-based rations but typically prohibit these technologies to meet standards requiring no hormones, no ionophores, and no non-therapeutic antibiotics. As a result, differences in performance and efficiency between production systems are affected by management and metabolic modifiers rather than diet composition (Cooprider et al., 2011; Smith et al., 2024; Smith et al., 2020).

Technologies used in conventional feedlots do not act through a single mechanism; rather, they operate through distinct and complementary pathways that support their combined use. Monensin is an ionophore that inhibits many gram-positive ruminal bacteria via disrupting ion gradients, shifting ruminal fermentation toward greater propionate production, reducing deamination and ammonia formation, and improving nitrogen efficiency (Russell and Strobel, 1989). Monensin improves feed efficiency by reducing dry matter intake (DMI) while maintaining, and sometimes increasing, ADG. Energy balance research further showed monensin increased the apparent efficiency of energy use for maintenance by 5.7% and reduced dry matter needed for maintenance by 5.4% (Byers et al., 1980). Thus, the response to monensin appears to reflect both ruminal microbial modulation and decreased DMI, thereby increasing the proportion of gross energy recovered as metabolizable energy. Tylosin is an antibiotic primarily used to reduce liver abscess incidence. Tylosin is fed alongside monensin in conventional feedlot systems rather than as a primary performance modifier alone (Nagaraja et al., 1999; Smith et al., 2024). Zinn (1987) showed monensin plus tylosin reduced feed intake, improved feed conversion by about 5%, and increased estimated dietary net energy values, while producing only minor changes in overall digestion. Monensin and tylosin contribute distinct but complementary functions within a conventional feedlot program. Furthermore, steroidal implants and β-adrenergic agonists enhance lean tissue accretion through divergent mechanisms, with implants acting primarily through anabolic hormonal signaling and β-adrenergic agonists altering nutrient partitioning through β-adrenergic receptor activation, thereby increasing lean gain and reducing the energetic cost of tissue accretion (Smith et al., 2020). Collectively, monensin, tylosin, steroidal implants, and β-adrenergic agonists improve feedlot production through distinct but complementary mechanisms affecting ruminal fermentation, animal health, nutrient partitioning, and lean tissue accretion, providing conventional systems with multiple avenues to improve production efficiency that are restricted or unavailable in natural production systems.

The complementary effects of these technologies become evident when conventional and natural production systems are compared at a common physiological endpoint. Smith et al. (2024) compared natural and conventional steers from weaning through finishing, with all steers marketed at a common shrunk slaughter weight. Using a common weight endpoint is important as natural and conventional cattle reach slaughter weight on different timelines. If cattle were slaughtered after the same number of days on feed, conventional steers would be heavier and more physiologically mature than natural steers, confounding comparisons of performance and carcass characteristics. Smith et al. (2024) found that conventional steers had greater ADG and feed efficiency than natural steers, and during finishing, G:F was about 21% greater in conventional cattle, requiring natural cattle to have more days on feed and more cumulative feed intake to reach the same endpoint. Similar outcomes were reported by Cooprider et al. (2011), with the only difference being that, because conventional cattle reached the target endpoint more efficiently, CH_4 and nitrous oxide (N_2O) emissions per finished steer and per unit of feedlot gain were lower than under natural management, linking feedlot technology use directly to sustainability outcomes. Similar conclusions have been reported in life-cycle assessments, where improved growth rate and feed efficiency consistently reduce the carbon footprint per kilogram of beef (Stackhouse et al., 2012; Rotz et al., 2015, 2019). Methane mitigation strategies, moreover, emphasize that increases in energy capture and feed efficiency reduce CH_4 intensity, whereas slower-growing systems increase CH_4 intensity (Hristov et al., 2013; Galyean and Hales, 2023). These differences in growth rate, days on feed, and energy capture translate directly into carcass composition. Smith et al. (2024) reported that natural steers, which remained on feed longer to reach the same slaughter weight, tended to have greater subcutaneous fat and higher yield grades, whereas conventional steers produced leaner carcasses with greater longissimus muscle area. Thus, the longer feeding period required under natural management allows cattle to reach greater physiological maturity, with subsequent weight gain increasingly represented by adipose deposition rather than proportional increases in lean tissue (NASEM, 2016). Cooprider et al. (2011) reported a similar pattern, noting that natural cattle would have been finished at a lighter body weight if slaughtered at the same carcass composition as conventional cattle due to earlier fat deposition in the absence of growth promotants. However, these data pertain only to steers, and feedlots typically house both steers and heifers, with conventional feedlot heifers receiving additional technology.

Conventional feedlot heifers will typically receive the active synthetic progestin melengesterol acetate (MGA). Melengesterol acetate suppresses estrus in heifers, which stabilizes feed intake and prevents the performance losses and behavioral disruptions associated with cyclic activity during finishing (NRC, 2016). In a large commercial feedlot study, Sides et al. (2009) compared heifers receiving monensin and tylosin with or without melengestrol acetate (MGA). Continuous MGA supplementation increased final body weight, ADG, DMI, and hot carcass weight and also increased marbling score, 12th-rib fat thickness, and the proportion of carcasses grading Choice or greater. The value of MGA is also evident in withdrawal responses. When MGA, monensin, and tylosin were withdrawn 35 days before slaughter, carcass weight and carcass quality traits were adversely affected relative to continuous feeding, and the authors noted that heifers returned to estrus shortly after MGA removal, which helps explain the decline in performance stability (Sides et al., 2009). Consistent with performance responses, MGA-fed heifers also produced heavier carcasses and improved quality-related endpoints, with higher hot carcass weight, greater marbling score, and a larger proportion of carcasses grading Prime or Choice than heifers not receiving MGA (Sides et al., 2009). Although continuous MGA supplementation improved growth performance and increased marbling, it was also associated with greater 12th-rib fat thickness and calculated yield grade and a smaller longissimus muscle area, indicating that the performance response was accompanied by greater carcass finish. This is an important distinction from the steer literature, where conventional technology more often increases muscling and carcass weight while reducing fatness at a common endpoint. This is because the biological effect of suppressing estrus in heifers alters both performance and the pattern of carcass deposition. Taken together, the heifer literature suggests that conventional and natural systems differ not only in access to generic growth-promoting technologies but also in access to sex-specific management tools that can stabilize intake, improve growth, and change carcass composition during finishing.

Regarding meat quality, there is limited evidence that natural beef is consistently superior when carcasses are matched for marbling. Keys et al. (2020) reported that longissimus lumborum from conventional and natural programs did not differ in pH, moisture, intramuscular fat, or basic composition when evaluated at the same quality grade. Previous studies indicate that the effects of growth-promoting technologies on beef quality vary depending on the trait, muscle, and postmortem aging period evaluated. Burnham et al. (1997) reported lower ultimate pH and greater Warner-Bratzler shear force in steaks from steers receiving growth promoting implants, whereas Watson (2008) found that effects on tenderness and palatability differed among muscles and aging periods. These data indicate that perceived differences in natural beef are largely attributable to production claims rather than consistent differences in eating quality.

Collectively, conventional feedlot systems reduce CH_4 intensity by improving biological efficiency, including faster growth, fewer days on feed, and lower DMI per unit of gain (Cooprider et al., 2011; Smith et al., 2024; Rotz et al., 2015, 2019). In contrast, natural systems, which exclude growth-promoting technologies, operate with lower efficiency and consequently produce greater CH_4 emissions per unit of beef at equivalent slaughter weights. These limitations highlight the need for alternative strategies to enhance efficiency and reduce CH_4 emissions within the constraints of natural production systems.

Energy Use and Methane

Differences in greenhouse gas (GHG) emissions between natural and conventional feedlot systems are only one component of total beef system emissions. Life-cycle analyses indicate that the grazing sectors of U.S. beef production, especially the cow-calf and stocker phases, account for about 70-80% of overall greenhouse gas output, largely due to these animals consuming high roughage diets and breeding stock remaining in the systems year-round while producing only one calf annually (Rotz et al., 2015, 2019). Throughout different production phases, CH_4 emissions per kilogram of carcass weight are greatest in cow-calf systems (370 g), compared to 61 g for stocker/backgrounding, and lowest during the finishing phase (51 g), which illustrates that the feedlot phase is not the largest source of CH_4 on a whole-system basis, but remains important when evaluating production efficiency (Rotz et al., 2019). Conventional feedlot systems do not eliminate methane production; however, they typically reduce CH_4 intensity by shortening the finishing period and decreasing cumulative feed use (Cooprider et al., 2011). The feedlot phase, therefore, has potential for nutritional intervention, as high-concentrate diets lower CH_4 emissions per unit of DMI by promoting propionate fermentation and increasing passage rates compared with forage-based systems.

At the animal level, CH_4 is not simply a waste gas but a product of how the rumen maintains fermentation under anaerobic conditions. The rumen is an ideal environment for methanogenesis because it is warm, oxygen-free, has readily available fermentable substrates, and supports microbial communities that are metabolically linked through interspecies transfer of reducing equivalents, especially hydrogen (H_2) (Greening et al., 2019). The mechanistic basis for CH_4 centers on H_2 disposal. During fermentation, bacterial, protozoal, archaeal, and fungal communities degrade carbohydrates to volatile fatty acids (VFA) which are a major source of metabolizable energy (ME) for the ruminant animal, while generating reduced cofactors and metabolic H_2. Methanogenic archaea consume H_2 as an electron donor, typically with carbon dioxide (CO_2) as the electron acceptor during anaerobic respiration, reducing it to CH_4 and H_2O. This maintains the low ruminal H_2 partial pressure required for continued microbial oxidation and energy (ATP) generation (Badhan et al., 2025; Janssen et al., 2010). Thus, methanogenesis is biologically useful to the rumen ecosystem but energetically unfavorable to the host animal, because feed energy that could otherwise be retained is instead lost as eructated gas. However, if H_2 is not removed, reduced cofactors will accumulate, fermentation becomes less thermodynamically favorable, and microbial carbohydrate degradation, growth, and protein synthesis can all be impaired (Beauchemin et al., 2008; Janssen et al., 2010; Thompson and Rowntree, 2020). Therefore, CH_4 production is beneficial to the rumen microbial ecosystem but inefficient for the host animal, as feed energy is lost as eructated gas rather than being conserved as ME.

Ruminal fermentation pathways determine the fate of metabolic H_2 and, consequently, the extent of methanogenesis. Pathways that favor acetate and, to a lesser extent, butyrate release H_2, whereas propionate formation is a H_2 sink and therefore competes directly with methanogenesis for reducing equivalents (Johnson and Johnson, 1995; Janssen, 2010). Thus, methanogenesis can benefit fermentative microbes by maintaining a low hydrogen partial pressure, even though the resulting methane is eructed and represents a loss of feed energy for the host animal (Badhan et al., 2025). High roughage diets tend to have greater CH_4 production because of the fibrolytic fermentation, higher acetate output, and longer retention of fermentable fiber in the rumen, whereas high-grain diets favor amylolytic and propionogenic pathways that reduce the H_2 that is available to methanogens (Johnson and Johnson, 1995; Hristov et al., 2013; Galyean and Hales, 2024). Because propionate serves as the primary precursor for hepatic gluconeogenesis, fermentation shifts toward propionate synthesis improve both energetic efficiency and glucose supply to the host (Allen and Bradford, 2012). Importantly, these responses are not driven solely by substrate composition. Passage rate influences ruminal hydrogen concentration indirectly through methanogen population dynamics. At higher passage rates, methanogens must grow faster to avoid being washed out of the rumen, which requires a higher steady-state H_2 concentration. The resulting increase in H_2 concentration suppresses H_2-producing fermentation pathways and favors the redirection of reducing equivalents toward propionate, thereby reducing H_2 production and CH_4 formation per unit of feed fermented (Janssen, 2010). However, faster passage rates can also reduce the time available for substrate digestion, so their effects on total methane production and host energy capture depend on the balance between altered fermentation and reduced digestibility (Hales, 2022). If a feed additive shifts fermentation toward propionate, less H_2 is produced and less CH_4 is formed. However, if a feed additive directly inhibits methanogens without reducing H_2 production, accumulated H_2 may be eructated, meaning energy could be lost as H_2 rather than captured as improved efficiency (Kinley et al., 2020). Under that scenario, reduced CH_4 production would not necessarily indicate improved energetic efficiency because reducing power is lost as H_2 rather than conserved in useful fermentation products.

The magnitude of CH_4 energy loss is best understood within the framework of classical energy partitioning. Methane represents a direct loss of GE, ranging from 2 to 12% of intake, with lower losses in high-grain diets and greater losses in forage-based systems (Johnson and Johnson, 1995). Gross energy intake (GEI) by the animal is reduced by fecal loss to yield digestible energy (DE), and losses in urine and gases, including CH_4, reduce the energy pool to ME, which then supports maintenance and tissue gain (Lofgreen and Garrett, 1968). High-grain feedlot diets are quite efficient, with ME:DE ratios exceeding 0.90 due to lower CH_4 and urinary losses compared with forage diets (Hales et al., 2014; Galyean et al., 2016).

Within finishing diets, roughage level and starch digestibility directly affect where energy is lost. Increasing alfalfa hay from 2 to 14% of a dry-rolled corn-based diet increased fecal and CH_4 energy losses and decreased retained energy as a fraction of GE, even though daily ME intake was similar (Hales et al., 2014). At the additive level, ionophores such as monensin are estimated to increase ME supply by ~1.5–2.3% by shifting volatile fatty acid (VFA) patterns toward propionate, reducing deamination, and modestly lowering CH_4 formation (Goodrich et al., 1984; Duffield et al., 2012; Galyean et al., 2016). Inhibitors like 3-nitrooxypropanol (3-NOP) can reduce CH_4 energy losses; in high-producing dairy cows, 3-NOP lowered CH_4 energy by about 3.8% of GEI, which accounted for a large share of the extra body weight gain when DMI and dry matter digestibility (DMD) were held constant, although H_2 eructation increased substantially (Hristov et al., 2015). Despite a 64-fold increase in H_2 emissions, the actual energy lost as H_2 was minimal relative to the CH_4 energy spared.

Methane represents an energy loss within the production system. Any intervention that reduces the proportion of GEI lost as methane, while maintaining DMI and DMD, increases the energy available for production. CO_2-equivalent emissions (CO_2e) are commonly used to compare greenhouse gases by expressing their climate effect relative to CO_2 over a specified time horizon, typically 100 years (Global warming potential (GWP_{100}) metric) (IPCC, 2021). Under this approach, emissions of each greenhouse gas are multiplied by its GWP to express CO_2-equivalent emissions. These energetic mechanisms explain why conventional programs, which improve growth rate and feed efficiency, consistently produce lower CH_4 and CO_2-equivalent emissions per unit of beef compared with natural systems.

Pollution Swapping

Research on enteric CH_4 has often treated the rumen as an isolated system, even though any change in fermentation inevitably alters the quantity and form of nutrients excreted in manure. Hristov et al. (2013) argued that mitigation options must be assessed at the whole-farm scale because a practice that lowers one gas or loss pathway can increase another or simply shift emissions from the animal to manure or soil. Evaluating a dietary additive solely on enteric CH_4 reduction therefore risks overlooking pollution swapping: reductions in CH_4 that are offset by increased emissions of other gases or by greater losses from downstream stages.

Rotz et al. (2019) showed that, in U.S. beef systems, enteric CH_4 from the cow–calf and stocker phases dominates total GHG emissions, but the feedlot phase contributes substantially via manure ammonia (NH_3) and manure-derived nitrous oxide (N_2O), especially in warmer, wetter regions and on heavier soils that favor gaseous nitrogen (N) losses. Faster growth and fewer days on feed consistently reduce CH_4 emitted per kilogram of carcass, yet Rotz et al. (2019) emphasized that the magnitude and form of N losses are driven at least as much by pen conditions, manure handling, and cropping practices as by what happens in the rumen.

Common dietary mitigation strategies illustrate how pollution swapping can arise. Increasing dietary concentrate and reducing forage lowers CH_4 yield because starch-rich diets push fermentation towards propionate and reduce the fraction of GE lost as CH_4 (Hristov et al., 2013). At the same time, these high-grain diets can depress fiber digestibility and deliver more fermentable organic matter and nitrogen to manure (Hristov et al., 2013). Under warm, damp feedlot conditions, the additional substrate can support higher CH_4 and N_2O formation during storage or following land application, particularly when manure is handled in liquid or semi-solid systems (Amon et al., 2006; van der Weerden et al., 2014; Rotz et al., 2019). For example, Amon et al. (2006) showed that aeration and straw covers reduced slurry CH_4 but increased NH_3 losses, whereas anaerobic digestion substantially lowered net greenhouse gas emissions but altered the balance between storage and field emissions.

Protein form provides an even more direct link between enteric processes and manure emissions. The common expectation is that replacing rumen-degradable protein (RDP) with rumen-undegradable protein (RUP) sources improves nitrogen-use efficiency and reduces urinary N, thereby lowering the potential for N_2O emissions. Coelho et al. (2022) challenged this assumption in a feedlot system, demonstrating that different RUP sources produced similar total N intake and excretion, but the timing and form of N losses differed, and some sources led to higher cumulative N_2O emissions from manure with little change in CH_4 or NH_3. These data are consistent with N-cycling analyses suggesting that many protein strategies redistribute N among fecal, urinary, and gaseous pools rather than reducing total N losses, and that whether N_2O rises or falls depends strongly on manure management and soil conditions (Hristov et al., 2011).

Strategies that redirect reducing equivalents away from methanogenesis can also introduce tradeoffs that complicate their overall environmental benefit. Nitrate, for example, is an alternative electron acceptor because it thermodynamically outcompetes CO_2 for reducing equivalents, and both *in vivo* and mechanistic work show substantial decreases in enteric CH_4 when nitrate partially replaces non-fiber carbohydrate in the diet (Hristov et al., 2013; Greening et al., 2019). However, Hristov et al. (2013) classify nitrate as a high-potential but high-uncertainty option due to safety margins being narrow; most studies have not followed nitrate-derived N through manure storage and soils to determine whether lower CH_4 is offset by higher N_2O. Without that information, it is impossible to determine whether nitrate offers a net climate benefit or if it is simply trading one greenhouse gas for another.

Collectively, national inventories and whole-farm models make it clear that manure NH_3 and manure-derived N_2O are components of the beef greenhouse-gas footprint (Hristov et al., 2013; Rotz et al., 2019). Yet most mitigation experiments with high-grain cattle report only enteric CH_4, sometimes accompanied by simple N balance, but rarely by integrated measurements of manure-stage CH_4, NH_3, and N_2O under the same dietary and additive treatments. Coelho et al. (2022) began to narrow this gap experimentally, and Rotz et al. (2019) integrated enteric, manure, and soil emissions at the modeling level, but long-term datasets capturing all four gaseous pathways are limited (Amon et al., 2006; van der Weerden et al., 2014).

Methane Mitigation Strategies

The CH_4 literature for feedlot cattle is now elaborate enough that a pattern emerges. Monensin selectively inhibits Gram-positive, hydrogen-producing bacteria, increases propionate, lowers the acetate:propionate (A:P) ratio, and at least initially decreases methane yield (MY) by 5–10% (Goodrich et al., 1984; Hristov et al., 2013; Appuhamy et al., 2013). Meta-analyses across feedlot studies report that monensin reduces DMI by about 3% and increases ADG by 2–3%, thereby improving G:F by 4–8% (Duffield et al., 2012; Marques and Cooke, 2021). Methane emissions are modest and inconsistent in high-grain diets; this, along with adaptation of the rumen microbiota to monensin over time, blunts the magnitude of methane reduction by monensin (Guan et al., 2006; Hristov et al., 2013). For natural systems, the key point is that this entire class of ionophore-based strategies is off-limits.

Some technologies attack methanogens directly, and 3-NOP is the most studied. It inhibits methyl-coenzyme M reductase, the terminal enzyme in CH_4 formation, and in doing so it can suppress MY by 30–80% depending on diet and dose (Dijkstra et al., 2018; Almeida et al., 2023). In dairy cows, 3-NOP decreased CH_4 production by 30% over 12 weeks with no impact on DMI or milk yield, and spared energy resulting in greater body weight gain (Hristov et al., 2015). In high-grain feedlot diets, increasing 3-NOP from 50 to 125 mg/kg DM reduced CH_4 yield by up to 87.6% and production by 90% without affecting ADG, G:F, or carcass traits (Almeida et al., 2023). Considering 3-NOP is a synthetic molecule, its acceptance by natural programs remains an open question.

Red macroalgae in the genus *Asparagopsis* may be a promising CH_4 mitigation strategy due to 3-NOP-like suppression with a natural label. *Asparagopsis taxiformis* and *A. armata* produce bromoform and related halomethanes that inhibit methyl-coenzyme M reductase

(Machado et al., 2014; Min et al., 2021). In vitro, small inclusions (< 2% of diet OM) reduce CH_4 production by 90-99% (Machado et al., 2014; Min et al., 2021). *In vivo*, feeding *A. taxiformis* at 0.2 to 0.5% of diet OM or via a canola-oil carrier has reduced CH_4 emissions by more than 80% in beef steers, with a few studies reporting concurrent improvements in G:F and exit weight (Kinley et al., 2020; George et al., 2024). Life-cycle modeling for Australia suggests that if Asparagopsis is used only in feedlots, national beef GHG emissions could fall by 1 to 4% by 2030, a modest contribution given the dominance of the cow–calf phase (Ridoutt et al., 2022). Supply and production costs, maintaining bioactive stability, regulatory concerns surrounding bromoform, and potential consumer concerns about feeding seaweed-derived halomethanes may all limit its use, particularly in natural production systems.

Fat supplements are used primarily to increase dietary energy density and can increase the energy available for growth or production when they replace fermentable carbohydrate without reducing DMI or fiber digestibility. Supplemental fat may also decrease CH_4 emissions by reducing DMI or limiting the amount of fermentable organic matter available for ruminal fermentation. Although biohydrogenation of unsaturated fatty acids can provide an alternative hydrogen sink, this likely contributes less to overall CH_4 mitigation than changes in intake and fermentable substrate supply (Beauchemin et al., 2008; Galyean and Hales, 2024). Unsaturated fats act as alternative hydrogen sinks, and many fats have mild anti-protozoal and anti-bacterial effects (Czerkawski et al., 1966; Johnson and Johnson, 1995; Beauchemin et al., 2008). Across studies, adding 3 to 4% plant oil or oilseed fat decreases CH_4 yield by 10 to 20%, provided total diet fat remains below 6 to 7% of DM to avoid depressing fiber digestibility (Beauchemin et al., 2008; Galyean and Hales, 2024). In grazing beef steers, supplementing whole cottonseed improved ADG and reduced CH_4 intensity, but responses depended on pasture quality and intake patterns (Beck et al., 2018, 2019). For feedlot cattle already consuming high-energy diets, the additional reduction in CH_4 from supplemental fat may be modest. The primary nutritional benefit is the increase in dietary energy density and potentially greater energy available for retention, provided dietary fat does not reduce fiber digestibility or DMI. Plant lipids are acceptable in natural programs, but cost, carcass fatness, and the diminishing returns on already high-energy diets limit how far this strategy can go.

Tannins and saponins occupy a middle ground; they are commonly derived from agro-industrial byproducts and have reproducible but moderate effects on CH_4 yield. Condensed tannins from *Acacia mearnsii* and other sources have reduced CH_4 emissions by 8-30% *in vivo*, but the effective window is narrow; higher doses depress intake and fiber digestion (Jayanegara et al., 2014; Min et al., 2021). In feedlot Nellore bulls, a proprietary tannin–saponin blend used as an addition to monensin reduced CH_4 emissions by 17.3% during the fattening phase without affecting ADG or carcass traits (Magnani et al., 2023).

Critically, almost all the above strategies were developed and tested in the context of conventional production. Synthetic inhibitors and stabilized bromoform may eventually be approved and accepted, but that is not guaranteed. Tannins and saponins are promising, but mitigations are moderate, and their application in high-grain diets is still limited. This provides an opportunity to find a natural CH_4 mitigation product that is plant-derived or by-product-based, acts at the rumen level on hydrogen and methanogens, and preserves growth. Globally, cashew processing is a textbook case of an underutilized agricultural waste stream. The global cashew market was valued at approximately USD 7.78 billion in 2024 and is projected to reach USD 11.67 billion by 2033 (Straits Research, 2020). Cashew shells account for about 70 to 75% of the nut mass (Cruz et al., 2024; Alasalvar et al., 2025). Historically, they have been incinerated for low-grade heat or discarded, even though they contain CNSL. The interest in CNSE and CNSL stems from the phenolic compounds in the oil, which have the potential to modify rumen fermentation and reduce enteric CH_4 emissions.

Cashew Production

The cashew tree (*Anacardium occidentale*) originated in South America and is now widely cultivated to supply edible cashews for human consumption; however, processing generates substantial quantities of non-kernel material that enters the waste stream or is diverted to byproduct uses. According to Watanabe et al. (2010), cashew production is concentrated in several regions worldwide, with Brazil, India, Kenya, Mozambique, and Tanzania supporting some of the largest cashew tree populations. Global raw cashew nut production in 2024 is estimated at approximately 5.4 million metric tons, with West Africa supplying the majority of the world's crop (International Nut and Dried Fruit Council, 2024). Cashew fruit development yields two main components: a fleshy accessory structure commonly referred to as the cashew apple and the true nut that contains the kernel. The apple accounts for the majority of the harvested biomass (approximately 88-92% of total fruit mass), which leaves a large amount of discarded material (Gutiérrez-Paz et al., 2024). The nut contains the edible kernel enclosed within a curved, kidney-shaped pericarp (shell) composed of four distinct layers: a firm outer skin (epicarp), a spongy, honeycomb-like mesocarp, a hard endocarp, and a thin papery testa that adheres closely to the kernel (Cruz et al., 2024; Gutiérrez-Paz et al., 2024). CNSL typically represents roughly one-third of the cashew shell's weight and is characterized by a high concentration of phenolic constituents, including anacardic acids, cardanol, and cardol (Kobayashi et al., 2016).

Regulation of Cashew Nut Shell Byproducts

The distinction between CNSE and CNSL, as defined by the Association of American Feed Control Officials (AAFCO) (Bubb, 2024), originates from differences in extraction methodology (cold pressing versus heat extraction), which subsequently influences chemical composition and functional applications. CNSL is a heat-processed product used as an antioxidant in fats and oils and must contain at least 55% cardanol and 10% cardol, with inclusion in complete feeds limited to 600 mg/kg. Although AAFCO defines it this way, new processing methods have emerged to preserve anacardic acid in some CNSL products, meaning they are cold-extracted rather than heat-extracted. In contrast, CNSE is defined as a cold-pressed extract from cashew shells, approved as a flavoring agent, with a maximum inclusion of 500 ppm in a complete cattle diet. CNSE is the appropriate term to describe commercial, cold-extracted cashew shell products formulated on a carrier (granules or liquids) and whose phenolic profile resembles that of cold extracted CNSL.

The functional and mechanistic properties of both CNSE and CNSL are fundamentally determined by their phenolic constituent profiles and the inherent bioactivity of those compounds. Commercial CNSE used as feed additives are typically cold-extracted, anacardic acid–rich products formulated on a carrier, and their biological effects closely resemble those of cold extracted CNSL (Watanabe et al., 2010; Danielsson et al., 2014). For example, CNSE products, such as those produced by Adisseo (DynOmik), are manufactured under conditions designed to avoid the high temperatures that drive anacardic acid decarboxylation, allowing the extract to contain at least 25% anacardic acid with lower concentrations of cardanol. Across studies, differences among cashew shell products in antimicrobial response largely reflect variation in phenolic composition, particularly the presence or absence of anacardic acid.

Differences in extraction conditions directly influence the chemical composition of cashew shell products.

Effects of Processing on Chemical Composition

Recent lipidomic analyses have shown that processing conditions substantially alter the chemical composition of cashew nut shell products. León et al. (2025) reported that thermal pretreatment, such as roasting or steaming, significantly reduced concentrations of several lipid classes, including triglycerides, glycerophospholipids, and fatty alcohols, compared with raw cashew shells. The method used to extract the oil also influenced the resulting lipid profile. Extraction with polar solvents such as acetone increased the abundance of lysophosphatidylcholines, phosphatidic acids, and sterol-related lipids, whereas mechanical pressing preserved higher concentrations of triglycerides and certain terpenoid compounds. These findings demonstrate that both pre-treatment temperature and extraction method strongly influence the chemical composition of CNSE and CNSL.

Gandhi et al. (2013) demonstrated that the efficiency of phenolic recovery from cashew nut shells is strongly influenced by solvent polarity and temperature during extraction. Polar ketonic solvents, such as methyl isobutyl ketone (MIBK), produced higher CNSE yields than non-polar solvents because they more effectively extract phenolic compounds from the shell matrix. Anacardic acid is thermolabile and readily decarboxylates to cardanol during high-temperature processing. Industrial distillation can therefore convert anacardic acid into cardanol, thereby altering the extract's phenolic profile. This thermal sensitivity provides a mechanistic explanation for the differences between cold-pressed CNSE, which retain anacardic acid, and heat-processed CNSL, which contains minimal anacardic acid. Consequently, extraction methods that minimize thermal exposure are necessary to preserve the phenolic composition associated with biological activity. These processing effects ultimately determine the relative abundance of the major phenolic compounds present in CNSE and CNSL**.** Kinetic work by Sangaré et al. (2025) helps explain this behavior. They described three stages of thermal degradation in cashew nut shell phenolics. First, anacardic acids undergo decarboxylation at approximately 150 °C, releasing CO_2 and converting to the less polar cardanols. Second, cardanols and cardols volatilize or break down into smaller fragments. Finally, remaining polyphenolic structures condense and degrade at temperatures above 400 °C. Because decarboxylation occurs at relatively low temperatures, common industrial processes such as roasting or distillation can rapidly convert anacardic acid to cardanol, thereby shifting the extract's phenolic profile (Sangaré et al., 2025; Sharma et al., 2020). This conversion reduces the biological activity associated with anacardic acid.

Phenolic Compounds

As mentioned previously, cold-extracted CNSE and CNSL contain a phenolic fraction dominated by three alkylphenols: anacardic acids, cardol, and cardanol (Sharma et al., 2020). These compounds share a common structural feature, a 15-carbon alkyl side chain, but differ in the degree of saturation of that chain, producing monoene, diene, and triene homologs (Lubi and Thachil, 2000). Variation in the functional groups on the aromatic ring further differentiates the three classes and contributes to differences in physicochemical behavior and bioactivity (Salehi et al., 2019; Sharma et al., 2020). The relative abundance of cashew-derived phenolic compounds is strongly influenced by the extraction method. Cold-extracted CNSL obtained through solvent or mechanical processes typically contains 60 to 70% anacardic acid, 10 to 20% cardol, and 3 to 10% cardanol (Lubi and Thachil, 2000; Watanabe et al., 2010). In contrast, heat-extracted CNSL contains only trace amounts of anacardic acid because thermal processing induces its conversion to cardanol, whereas cardol concentrations remain largely unchanged (Lubi and Thachil, 2000; Watanabe et al., 2010). These compositional differences are central to biological activity, as antimicrobial potency consistently increases with anacardic acid concentration and decreases as cardanol becomes the dominant phenolic (Wakai et al., 2021). All three alkylphenols disrupt bacterial cell membranes through surfactant-like activity, though the potency order is consistently anacardic acid > cardol > cardanol (Kubo et al., 1993; Wakai et al., 2021)

Anacardic Acid

Anacardic acid is a salicylic-acid–type alkylphenol that includes a C15 side chain attached to an aromatic ring bearing both a hydroxyl (–OH) group and a carboxyl (–COOH) group (Salehi et al., 2019). The unsaturation pattern of the C15 chain is an important determinant of activity; in particular, the triene form (C15:3) has been reported to exhibit greater antioxidant and enzyme-inhibitory effects than the corresponding monoene or diene forms (Morais et al., 2017). These structural differences additionally influence physicochemical properties. Because anacardic acid contains both a carboxyl and a phenolic hydroxyl group, it is generally more polar than cardol, which lacks a carboxyl group and contains only phenolic hydroxyl functionalities (Wakai et al., 2021).

Cardol

Cardol is a resorcinol derivative containing two hydroxyl groups positioned in a meta configuration on the benzene ring, along with a C15 alkyl side chain (Lubi and Thachil, 2000). The dual hydroxyl configuration is important in cardol's biological activity (Sharma et al., 2020). Wakai et al. (2021) further demonstrated that the presence of two identical hydroxyl groups contributes to strong hydrophilicity, enhancing surfactant properties and antimicrobial efficacy against rumen bacteria, although these effects are less than those observed with anacardic acid.

Cardanol

Cardanol is the third major phenolic component of CNSE and is classified as a monohydroxy phenol due to the presence of a single hydroxyl (–OH) group on its meta-substituted aromatic ring (Lubi and Thachil, 2000). Its efficacy is considerably lower than that of anacardic acid and cardol, which is attributed to the presence of only a single hydrophilic hydroxyl group (Wakai et al., 2021).

Mode of Action of CNSE/CNSL in Ruminants

In vitro Approaches

Evaluation of novel feed additives relies on *in vitro* fermentation systems that enable rapid, cost-effective screening before progressing to animal trials. Batch culture techniques are commonly used for preliminary assessment of additive effects on gas production and fermentation end products, whereas semicontinuous systems such as the Rumen Simulation Technique (RUSITEC) permit longer-term evaluation of fermentation stability and dose–response relationships under controlled conditions (Watanabe et al., 2010; Sarmikasoglou et al., 2024). In addition, pure culture assays can identify selective antimicrobial activity and determine the minimum inhibitory concentrations (MIC) of additives against specific rumen microorganisms (Watanabe et al., 2010). *In vitro* systems do not replicate the physiological conditions of the rumen. Closed batch cultures allow VFA to accumulate over time, whereas *in vivo* VFA are continuously absorbed across the rumen epithelium, potentially altering microbial growth dynamics along with CH_4 production patterns (Danielsson et al., 2014). Moreover, transferring rumen contents into closed fermentation vessels has the potential to disrupt microbial community structure, particularly among methanogenic archaea, complicating extrapolation of *in vitro* results to live animals (Danielsson et al., 2014).

Antimicrobial Effects of CNSE and CNSL

The antimicrobial activity of CNSE largely results from its phenolic composition, particularly anacardic acid, which is retained in cold-extracted products but is largely absent in heat-processed CNSL (Kubo et al., 1993; Hamad and Mubofu, 2015). The biological activity of CNSE and CNSL is directly relevant to rumen function, as these antimicrobial properties directly influence rumen microbial ecology and fermentation pathways. Cold-extracted CNSE exhibits antimicrobial activity against select rumen microorganisms (Watanabe et al., 2010; Danielsson et al., 2014). Rather than broadly suppressing microbial growth, CNSE selectively inhibits bacterial groups associated with hydrogen and formate production, altering fermentation pathways.

In batch culture experiments, Watanabe et al. (2010) evaluated both raw (anacardic-acid–rich) and heated (cardanol-rich) CNSL sourced from India. The unheated product reduced CH_4 production and increased propionate formation more effectively than monensin when evaluated under identical conditions, whereas heated CNSL showed only modest effects (Watanabe et al., 2010). In semicontinuous RUSITEC systems using the same raw CNSL, increasing inclusion rate produced progressive reductions in CH_4 output and corresponding increases in propionate, resulting in a dose-dependent response (Watanabe et al., 2010). These data indicate that cold-extracted CNSE and CNSL alter fermentation patterns in a manner consistent with reduced hydrogen availability for methanogenesis. Importantly, these responses were consistently associated with unheated, anacardic-acid–rich preparations, whereas heat-treated, cardanol-rich

CNSL exhibited substantially weaker antimicrobial and CH_4 reducing effects (Watanabe et al., 2010).

When compared with studies using commercial CNSE products, Watanabe (2010) cold-extracted CNSL work generally reports larger absolute shifts in CH_4 production and VFA profiles, which is consistent with higher effective anacardic acid exposure in cold-extracted CNSL. In contrast, Danielsson et al. (2014) used a cold-extracted CNSL in an automated gas system and observed a more moderate CH_4 inhibition (approximately 8-18%) but a similar directional response, including the suppression of hydrogen-associated taxa and the enrichment of succinate- and propionate-producing genera. These differences likely reflect variation in product formulation (CNSL vs carrier-based CNSE), inclusion rate, and experimental system. Across studies, the biological response is consistent: anacardic-acid–rich products reduce hydrogen-producing bacteria and methanogens while favoring alternative hydrogen sinks.

CNSE has demonstrated CH_4 reducing activity across multiple *in vitro* systems. In short-term batch incubations, CNSE decreased total gas and CH_4 production while shifting the VFA profile toward greater propionate formation relative to both the control and monensin treatments (Sarmikasoglou et al., 2024). In dual-flow continuous culture, CNSE supplementation reduced the abundance of Gram-positive fibrolytic bacteria and increased the abundance of propionate-associated taxa, resulting in fermentation shifts comparable to those observed with monensin (Sarmikasoglou et al., 2024). Relative to Watanabe's cold-extracted CNSL work, these responses were smaller in magnitude but directionally consistent, which likely reflects lower effective anacardic acid doses and differences in product formulation. Complementary work in dual-flow continuous culture by Compton et al. (2023) evaluated a commercial, cold-extracted CNSE (59% anacardic acid, 18% cardol) in a high-producing dairy cow diet. In contrast to the larger fermentation shifts observed in batch and semicontinuous systems, CNSE supplementation resulted in minimal changes in pH, VFA profiles, DMD, with fermenters converging on a steady state similar to the control. When considered alongside Watanabe et al. (2010), Danielsson et al. (2014), and Sarmikasoglou et al. (2024), these results indicate that the magnitude of CNSE responses varies with product formulation, inclusion rate, and experimental system.

Mechanistic insight from Watanabe et al. (2010) demonstrates that responses to cold-extracted CNSL are driven by selective microbial inhibition rather than indiscriminate toxicity. In pure-culture experiments, hydrogen- and formate-producing Gram-positive bacteria, including *Ruminococcus flavefaciens*, *R. albus*, and *Butyrivibrio fibrisolvens*, were inhibited at relatively low concentrations of cold-extracted CNSL, whereas propionate-associated Gram-negative species such as *Selenomonas ruminantium* and *Megasphaera elsdenii* tolerated substantially higher inclusion rates (Watanabe et al., 2010). This pattern was not observed with heat-treated CNSL, reinforcing that anacardic acids, rather than cardanol, are the primary active compounds. When considered alongside responses reported by Danielsson et al. (2014), these data indicate that cold-extracted CNSE and CNSL do not function as broad-spectrum antimicrobials, but instead selectively suppress microbial populations that generate hydrogen and formate, thereby shifting reducing equivalents away from methanogenesis and toward propionate formation.

Dietary context further influences the efficacy of CNSE-type products. Oh et al. (2017) showed that CNSL effectively reduced CH_4 and increased propionate across a wide range of forage-to-concentrate ratios (5:5 to 1:9), with efficacy exceeding that of monensin, which only reduced CH_4 under the highest concentrate diet (1:9 forage:concentrate ratio). Specifically, monensin produced a 46% reduction in CH_4 but only at that single dietary condition, whereas CNSL reduced CH_4 by 46-51% across three different forage:concentrate ratios and enhanced propionate under all diets tested. When evaluated alongside Watanabe et al. (2010) and Danielsson et al. (2014), selective inhibition of Gram-positive hydrogen producers by anacardic-acid–rich products are relatively robust to changes in dietary substrate, whereas ionophore responses are more diet-dependent.

The CH_4 mitigating potential of CNSL has also been evaluated under feedlot-relevant *in vitro* conditions. Using ruminal fluid from feedlot cattle fed a steam-flaked-corn finishing diet containing monensin and the same diet as the *in vitro* substrate, Beck et al. (2025) evaluated an anacardic-acid–rich, cold-extracted CNSL (62% anacardic acid in the ether extract fraction). In high-concentrate diets, CNSL reduced CH_4 production by approximately 20% without affecting *in vitro* DMD. Consistent with a hydrogen-redirecting mechanism, CNSL increased propionate concentration and reduced the A:P ratio, denoting a shift in fermentation stoichiometry rather than a reduction of overall microbial activity. Taken together, these studies suggest that anacardic-acid-rich CNSL can reduce CH_4 production in high-concentrate diets, likely through a shift in fermentation toward propionate without reducing digestibility. However, because Beck et al. (2025) evaluated CNSL *in vitro* in a diet containing monensin, *in vivo* research is still needed to determine whether this response occurs independently of monensin and is maintained in the animal.

Although monensin, CNSE, and CNSL products produce similar effects on fermentation outcomes, their mechanisms differ. Ionophores alter ion transport across the membranes of Gram-positive bacteria, disrupting cellular energetics and indirectly favoring propionate-associated pathways (Bergen and Bates, 1984). In contrast, anacardic acid rich CNSE and CNSL act through a membrane-targeting mechanism in which phenolic compounds insert into and disrupt microbial cell membranes (Oh et al., 2017; Hamad and Mubofu, 2015). This difference explains the observed selectivity: Gram-positive bacteria lack an outer membrane and are therefore more susceptible, whereas Gram-negative bacteria possess an outer membrane that limits permeability to hydrophobic compounds (Oh et al., 2017; Badhan et al., 2025).

At the cellular level, microscopic observations support this mechanism. Exposure of Gram-positive rumen bacteria to cold-extracted CNSL or purified anacardic acids results in membrane deformation, irregular cell surfaces, and defective septum formation, leading to elongation and eventual cell lysis, whereas Gram-negative species maintain relatively intact envelopes under similar conditions (Oh et al., 2017). Similar structural disruption has been observed in methanogenic archaea, where exposure to anacardic acid rich CNSL damages the cytoplasmic membrane and promotes leakage of intracellular contents, although susceptibility varies among taxa (Wakai et al., 2021).

These organism-level effects scale to predictable shifts in microbial community structure. Across *in vitro* systems, CNSE and CNSL supplementation consistently reduce Gram-positive fibrolytic and hydrogen-producing bacteria as well as methanogens, while maintaining or increasing Gram-negative, propionate-associated taxa (Danielsson et al., 2014; Oh et al., 2017; Sarmikasoglou et al., 2024; Maeda et al., 2021). From a mechanistic perspective, this selective antimicrobial pressure diverts metabolic H_2 away from methanogenesis toward alternative sinks, such as propionate formation, although the magnitude of the response varies with product, dose, and microbial community composition.

Whether alternative hydrogen sinks are activated depends on the degree of direct methanogen inhibition versus secondary H_2 starvation. Wakai et al. (2021) demonstrated that anacardic acid at 200 μg/mL directly disrupted methanogen cell membranes, confirming that direct archaeal suppression is possible at sufficiently high concentrations. However, at the ruminal concentrations achieved by most feedlot doses, the dominant antimicrobial effect is against Gram-positive hydrogen-producing bacteria (Oh et al., 2017), meaning methanogen populations decline partly because their primary substrate is less available. When methanogenesis is directly inhibited and H_2 accumulates, chain elongation (reverse beta-oxidation) can serve as an alternative hydrogen sink, producing medium-chain fatty acids including caproate and heptanoate (Guyader et al., 2017). Mitsumori et al. (2014) reported that CNSL feeding increased ruminal H_2 concentration alongside propionate, consistent with partial redirection rather than complete H_2 capture. This carries practical implications: if the dominant effect is reduced H_2 supply rather than direct methanogen killing, the energetic benefit of CNSE may be limited compared with strategies that directly inhibit methanogenesis, because some hydrogen that would have formed CH_4 may simply be eructated rather than redirected to glucogenic VFA.

In vivo evidence also supports the idea that CNSL can alter hydrogen utilization by reducing methanogenesis and redirecting reducing equivalents toward alternative fermentation pathways. Mitsumori et al. (2014) reported that supplementation with an anacardic-acid–rich CNSL pellet reduced CH_4 emissions and shifted VFA profiles toward increased propionate and hydrogen production, consistent with redistribution of H_2 which represents the pool of reducing equivalents generated during carbohydrate fermentation that must be consumed to sustain rumen fermentation. Similarly, Maeda et al. (2021) observed reduced MY and corresponding shifts in microbial populations in grazing beef cattle. Compared with *in vitro* systems, *in vivo* responses are generally smaller but directionally consistent, reflecting lower effective doses, longer adaptation periods, and greater system complexity.

Overall, current evidence indicates that natural cold-extracted CNSE and CNSL shift rumen fermentation through selective antimicrobial pressure that constrains H_2 producing and methanogenic pathways while favoring propionate synthesis. This research indicates that anacardic acid concentration and extraction method strongly influence response, and diet, dose, and microbial community structure contribute to variability in observed outcomes. Remaining gaps include the persistence of these responses under long-term feeding conditions and the extent of animal variation in response to CNSE supplementation.

Animal Trials and Performance

Although *in vitro* systems provide mechanistic insight, validation under *in vivo* conditions is necessary to determine whether these responses persist under practical feeding conditions. Across studies, the most important factor is whether the product retains a high concentration of anacardic acid, rather than the total inclusion of CNSL or CNSE in the diet. This makes it essential to distinguish cold-extracted CNSL from heat-extracted CNSL (cardanol-rich) and from cold-extracted CNSE products diluted on carriers. Most mechanistically complete *in vivo* work to date evaluated unheated CNSL or CNSE products that retain high proportions of anacardic acids, commonly sourced from Japan (Oh et al., 2017; Kobayashi et al., 2016).

The most detailed research with dairy cattle is studies testing cold-extracted CNSL in non-lactating Holstein cows (Shinkai et al., 2012; Mitsumori et al., 2014). Shinkai et al. (2012) fed CNSL in pelleted form following Watanabe et al. (2010) at a rate providing approximately 14 g anacardic acid/d (4 g CNSL/100 kg BW) and measured gas exchange in respiration chambers. Two pellet formulations were tested. The first, made of CNSL and silica only, reduced CH_4 38% but depressed DM and GE digestibility. The second, a nutritionally balanced pellet with CNSL blended into alfalfa meal, rice bran, and molasses, achieved a 19% CH_4 reduction with no depression of DMI, GEI, or total-tract digestibility. Rumen fermentation shifted in the expected direction, with decreased total VFA concentration and molar proportion of acetate, increased molar proportion of propionate, and a reduced A:P ratio, whereas rumen pH, protozoal counts, and total archaeal abundance remained largely unchanged (Shinkai et al., 2012). In contrast, Omoruyi et al. (2024) fed a cold-extracted CNSE product delivering 5 g product/d with no anacardic acid concentration provided and found no effect on total tract digestibility, milk yield, or CH_4 emissions in post-peak lactating Holstein cows. Follow up analysis showed that these responses were driven by changes in hydrogen partitioning rather than reduced microbial activity (Mitsumori et al., 2014). Therefore, Mitsumori et al. (2014) showed that the proportion of H_2 recovered in CH_4 decreased, whereas hydrogen recovery in propionate and dissolved H_2 increased, with only modest changes in total VFA production. Importantly, total hydrogen recovery remained near 90%, indicating a redistribution of reducing equivalents rather than a loss of fermentation capacity (Mitsumori et al., 2014). Together, these studies show that when anacardic-acid–rich CNSL is delivered at a sufficient dose, CH_4 can be reduced substantially by redirecting hydrogen toward glucogenic pathways without negatively affecting intake, digestibility, or energy retention.

This hydrogen shift has also been observed in grazing beef systems. Maeda et al. (2021) supplemented Lai Sind cattle with a cold-extracted CNSL at approximately 4 g/100 kg BW utilizing the same product as Shinkai et al. (2012), and Watanabe et al. (2010). The CNSL was provided in pellet form with a silica carrier mixture blended with molasses and concentrate before feeding. Methane yield measured in a respiration chamber decreased by approximately 20 to 24%, with no effects on DMI or apparent digestibility of NDF. These findings confirm that the hydrogen redirecting effect of cold-extracted CNSL is reproducible across both dairy and beef production systems.

When CNSL is heat processed, ruminal responses to its supplementation are minimal. Heat processed CNSL, which is dominated by cardanol due to thermal decarboxylation of anacardic acid, has consistently shown little biological activity. In lactating dairy cows, supplementation with 30 g/d of heat-processed CNSL (73% cardanol, 16% cardol, 3% methylcardol, with negligible anacardic acid) did not affect CH_4 emissions, DMI, milk yield, or milk composition (Branco et al., 2015). Similar results have been reported elsewhere, with only minor numerical changes in MY and no consistent effects on digestibility or performance.

At low doses, even unheated CNSL is relatively ineffective in reducing CH_4 production. In a commercial dairy setting, supplementation with 10 g/d of a CNSL product did not affect intake, milk yield, or milk composition, and daily CH_4 production remained unchanged (Gaspe et al., 2024). However, MY and the fraction of GEI lost as CH_4 (Ym) were slightly reduced, and in vitro incubations showed modest decreases in CH_4 and total VFA production. In transition cows, supplementation with 5.0 g/d of unheated CNSE granule (2.5 g CNSE/d; 1.5 g anacardic acid/d) decreased ruminal ammonia concentrations, and increased postpartum DMI and milk yield, indicating improved fermentation efficiency and nitrogen utilization (Goetz et al., 2023). However, CH_4 was not measured in this study. In contrast, when CNSE was fed to post-peak lactating cows at similar inclusion rates, there were no effects on DMI, milk production, or CH_4 emissions (Omoruyi et al., 2024). This contrast suggests that physiological state influences response, with greater effects observed during periods of high metabolic demand such as early lactation.

In beef cattle, responses to CNSE depend strongly on diet. In high-grain finishing systems, supplementation with 5 g/d of cold-extracted CNSE reduced CH_4 production by approximately 28 to 29% and simultaneously increased DMI, ADG, and final body weight, with a tendency for improved feed efficiency (Cuervo et al., 2025). These responses were associated with increased propionate molar proportion and a tendency for decreased acetate molar proportion, along with improved DMD, indicating enhanced hydrogen utilization toward glucogenic pathways. In contrast, similar doses in forage-based systems produce weaker and more variable responses. In cattle fed a backgrounding diet, CNSE supplementation at approximately 3 to 4 g/d did not affect intake, gain, or efficiency, but reduced CP digestibility while not consistently reducing CH_4 emissions (Cuervo et al., 2024).

Overall, *in vivo* responses to CNSL and CNSE are determined by anacardic acid concentration, which varies by product source and processing method. Cold-extracted products from Idemitsu Kosan (62% anacardic acid) and SDS Biotech (59% anacardic acid) reduced CH_4 and shifted fermentation toward propionate when sufficient anacardic acid was delivered, though performance effects ranged from positive to negative depending on carrier formulation, dose, and diet. Heat-processed CNSL (0% anacardic acid) had no biological activity at any practical dose (Branco et al., 2015). However, anacardic acid concentration is not consistently reported across studies, making it difficult to determine whether null responses reflect differences in product composition, insufficient dose, or genuine biological resistance.

Conclusion

Enteric CH_4 represents a significant source of energy loss and greenhouse gas emissions in beef feedlot systems, with these losses further amplified in natural programs that exclude conventional performance-enhancing technologies. Existing CH_4 mitigation tools generally have modest effects or lack compatibility with natural production standards. CNSE is a promising, agricultural waste-derived feed additive capable of reducing methane emissions and altering rumen fermentation; however, its efficacy is variable, and evidence in high-grain, natural feedlot systems remains limited. Rigorous evaluation of CNSE under these specific conditions is essential to determine its practical value for improving growth efficiency and reducing MY in beef cattle.

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Chapter 2 - Influence of cashew nut shell extract on enteric methane emissions, ruminal fermentation, and animal performance of finishing natural heifers

Abstract

Enteric methane (CH_4) from feedlot cattle is both a greenhouse gas and an energetic loss, diverting 2 to 12% of dietary gross energy (GE). Cashew processing produces large quantities of waste, some of which can be refined into cashew nut shell extract (CNSE), a phenolic-rich supplement containing anacardic acid. This study evaluated effects of CNSE supplementation on methane emissions, animal performance, feeding behavior, and carcass characteristics in finishing heifers. Sixty crossbred heifers (initial body weight = 515 ± 9 kg) were assigned to 1 of 4 treatments (n = 15/treatment): 0, 2.5, 5.0, or 7.5 g CNSE/heifer daily for 105 d. The CNSE (DynOmik, Adisseo, Alpharetta, GA) contained at least 25% anacardic acid. The finishing diet contained (DM basis) 23% corn silage, 20% distillers' grains, 55% corn, and 3% vitamin/mineral supplement. Intake and feeding behavior were recorded using an Insentec Roughage Intake Control (RIC) system (Hokofarm, Emmeloord, The Netherlands). Methane emissions were measured using an automated head chamber system (AHCS; GreenFeed; C-Lock Inc., Rapid City, SD). Relative to control, supplementation with 2.5 g/d CNSE increased dry matter intake (DMI) (12.64 vs. 11.86 kg/d), whereas supplementation of 5.0 (11.00 kg/d) and 7.5 g CNSE/d (10.72 kg/d) reduced DMI (cubic $P = 0.005$). Average daily gain (ADG) decreased linearly ($P = 0.02$) with lower ADG at the higher CNSE inclusion rates (1.31, 1.34, 1.17, and 1.17 kg/d for 0, 2.5, 5.0, and 7.5 g CNSE/d). Gain:feed ratio was not affected by treatment ($P \geq 0.33$). Heifers supplemented with 2.5 g CNSE/d had the greatest meal size (1.85 kg/meal), whereas meals per day increased with CNSE inclusion (linear $P = 0.03$) and eating rate decreased as CNSE inclusion increased (linear $P = 0.03$). Methane production (g/d) was not different among treatments ($P \geq 0.26$). Methane yield (g/kg DMI), CH_4 intensity (g/kg ADG), and Ym (% of gross energy) tended to exhibit a cubic response to CNSE supplementation, with the 2.5 g/d

treatment numerically lower than the 0. 5.0, and 7.5 g/d treatments (cubic $P = 0.095$, 0.092, and 0.077, respectively). Carcass characteristics, including fat thickness, ribeye area, hot carcass weight, marbling score, quality grade, and calculated yield grade were not affected by treatment ($P \geq 0.33$). Supplementation with CNSE altered feeding behavior and reduced growth performance at 5.0 and 7.5 g CNSE/d. Overall, CNSE supplementation did not reduce absolute CH_4 production, but the nonlinear responses in CH_4 yield, CH_4 intensity, and Ym suggest that a low dose of 2.5 g/d may provide modest methane mitigation without compromising growth performance.

Introduction

Enteric methane (CH_4) production from beef cattle has both environmental and energetic consequences because CH_4 is a greenhouse gas and represents a loss of approximately 2 to 12% of dietary gross energy, depending on diet composition (Johnson and Johnson, 1995). Enteric CH_4 emissions are commonly expressed as carbon dioxide equivalents (CO_2e) using the 100-year global warming potential (GWP_{100}). The IPCC Sixth Assessment Report assigns biogenic CH_4 a GWP_{100} of 27.2, meaning that 1 kg of CH_4 is equivalent to 27.2 kg of CO_2 over a 100-year time horizon (IPCC, 2021). Because CH_4 has a greater GWP_{100} than CO_2, enteric methane can contribute substantially to the greenhouse gas (GHG) footprint of beef production despite being emitted in smaller quantities.

Plant-derived feed additives have been evaluated as potential CH_4 mitigation strategies in ruminants. Cashew nut shell extract (CNSE) and cashew nut shell liquid (CNSL) are of particular interest because they are derived from a cashew-processing byproduct and can contain three phenolic compounds: anacardic acid, cardol, and cardanol (Danielsson et al., 2014). However, CNSE and CNSL are not interchangeable because processing alters their phenolic composition. Raw CNSL contained 62.3% anacardic acid, whereas heating eliminated detectable anacardic acid and increased cardanol to 73.9% of the phenolic fraction (Watanabe et al., 2010). This is relevant because heat causes anacardic acid to decarboxylate to cardanol during extraction or refining, increasing the relative cardanol fraction in heat-processed products (Lubi & Thachil, 2000).

Regarding the phenolic compounds, anacardic acid has antimicrobial activity against gram-positive ruminal bacteria and methanogenic archaea making it applicable to natural feeding programs while providing a use for an agricultural byproduct (Kubo et al., 1993; Watanabe et al., 2010). This selective inhibition redirects metabolic hydrogen toward propionate, which serves as an alternative hydrogen sink and reduces substrate availability for methanogenesis (Shinkai et al., 2012). Reports of in vivo CH_4 reductions range from 19% to 38% in dairy cattle (Shinkai et al., 2012) and up to 28% in finishing beef steers (Cuervo et al., 2025), though results have been inconsistent across product types and dosages (Branco et al., 2015; Compton et al., 2023). A key source of this variation is the extraction method: cold-processed CNSE retains anacardic acid in its active form, whereas heat-processed products contain mostly cardanol and lack antimicrobial activity (Watanabe et al., 2010; Danielsson et al., 2014).

Despite these findings, research is limited on the dose response to CNSE in finishing cattle, particularly under natural production systems. The present study was designed to fill that gap by evaluating supplemental CNSE (DynOmik, Adisseo, Alpharetta, GA; at least 25% anacardic acid) across a range of doses for effects on enteric CH_4 emissions, ruminal fermentation, feeding behavior, growth performance, and carcass characteristics in heifers fed a high-concentrate finishing diet under natural program conditions. We hypothesized that CNSE would reduce CH_4 emissions and increase propionate concentration in a dose-dependent manner.

Materials and Methods

All procedures involving animals were approved by the Kansas State University Institutional Animal Care and Use Committee.

Animals and Treatments

One hundred crossbred heifers (initial body weight = 517 ± 9 kg) were sourced from an auction house in northeastern Kansas. Heifers were vaccinated according to standard natural feedlot receiving protocols prior to shipment. Cattle were received at the Kansas State University Feed Intake Facility. Upon arrival, animals were provided ad libitum access to prairie hay and water for 2 d, then weighed, fitted with high-performance electronic identification ear tags (Allflex HDX Ultra EID Tag; Dallas, TX), and assessed for health status by research personnel.

Heifers were housed in a 61 × 24 m pen containing a covered 9 × 24 m concrete pad adjacent to the feed bunks, with the remainder of the pen consisting of a dirt surface. The pen was equipped with an Insentec Roughage Intake Control (RIC) system (Hokofarm, Emmeloord, The Netherlands) consisting of 18 automated feeding stations. The system continuously recorded individual dry matter intake (DMI), feeding duration, visit frequency, and meal size using electronic identification ear tags for animal recognition. Data were time-stamped and transmitted nightly to a central server, and weekly extracts of daily intakes and associated feeding behavior metrics were compiled.

During a 45-d acclimation period, heifers were transitioned from a high-roughage diet to a concentrate-rich finishing ration. This transition consisted of two step-up diets, after which heifers were maintained on the finishing diet for 14 d prior to initiation of the experiment. The finishing diet consisted of (DM basis) 20% corn silage, 20% distillers' grains, 57% corn, and 3% non-medicated mineral supplement (Table 1) and was fed once daily at 0600 h.

During the acclimation period, heifers were trained to use an automated head chamber system (AHCS; GreenFeed; C-Lock Inc., Rapid City, SD) for measurement of CH_4 and CO_2 emissions. The AHCS allows animals to voluntarily enter the system, where electronic identification recognizes the animal and dispenses a small amount of bait feed while exhaled air is collected for gas analysis (Hristov et al., 2015). When a heifer placed its head in the sampling hood, air was drawn from around the muzzle across gas analyzers by a fan generating a negative pressure (Hristov et al., 2015). Alfalfa pellets were fed as bait to encourage animals to remain in the unit during sampling. Ten individual pellet drops were collected and weighed from the AHCS unit averaging 36 ± 2.92 g (mean ± SD) per drop. Each visit was limited to a maximum of six pellet drops delivered at 30-s intervals, with a minimum interval of 4 h between feeding sessions to promote visits throughout the day.

Sixty of the 100 heifers were selected for use in the experiment. Animals that did not adequately adapt to the Insentec feeding system or the AHCS unit during the acclimation period were not used. Once the final 60 heifers were identified, heifers were ranked according to pre-trial AHCS visitation frequency and grouped by rank into 15 sets of 4 heifers. Heifers within each set of four were stratified by body weight across treatments (n = 15 heifers per treatment). This approach ensured that AHCS visitation frequency and initial body weight were balanced among treatments.

Treatments included a control diet without CNSE (0 g CNSE/d), and diets supplemented with 2.5, 5.0, or 7.5 g CNSE/heifer daily. The CNSE (DynOmik; Adisseo, Alpharetta, GA) contained a minimum of 25% anacardic acid as the primary bioactive compound. The 18

Insentec RIC bunks within the pen were randomly assigned to treatments (Figure 1), with 5 bunks allocated to the control treatment, 5 bunks to 2.5 g CNSE/d, 4 bunks to 5.0 g CNSE/d, and 4 bunks to 7.5 g CNSE/d. Each heifer was electronically restricted to its assigned set of 4 or 5 bunks through the Insentec system, allowing heifers access to only their assigned treatment diet.

The concentration of CNSE included in each treatment ration was calculated using the average DMI of heifers within each treatment. Weekly treatment-level DMI averages were used to adjust CNSE inclusion so that the target daily dose (g CNSE/heifer daily) was maintained throughout the study. Because cattle were fed for ad libitum intake, actual CNSE intake varied among animals within treatment dependent on DMI, but average intakes of CNSE across heifers within a treatment were consistent.

Treatments began on d 1 and were fed for a total of 105 d. Body weights were recorded on d 0, 1, 42, 77, 105, and 106 prior to feeding. All cattle were restrained in a hydraulic squeeze chute with a head gate during weighing and sampling procedures to minimize movement and ensure handler safety. Rumen fluid, fecal, and urine samples were collected prior to feeding on d 0 (before treatment initiation), 42, 77, and 105.

Feed Collection

Experimental diets were formulated as high-concentrate finishing diets and consisted of corn silage, distillers grains, dry-rolled corn, and a mineral-vitamin premix. On a dry matter basis, diets contained approximately 22.8% corn silage, 19.5% distillers grains, 54.5% corn, and 3.2% premix. Treatments consisted of 0, 2.5, 5.0, or 7.5 g of cashew nut shell extract (CNSE; DynOmik, Adisseo, Alpharetta, GA) per heifer daily. Cashew nut shell extract was added separately to the respective treatment diets during mixing. Ingredient composition and analyzed chemical composition of the experimental diet are presented in (Table 1) with mean weather across entire trial and periods summarized in (Table 2).

Feed samples were collected weekly, with additional samples collected on each animal sample collection day. On each feed sampling day, samples of the individual ingredients used to prepare the experimental diets were collected. Following mixing, multiple grab samples of each treatment ration were obtained throughout feed delivery as the ration was distributed across the assigned bunks.

Rumen Fluid Collection

Rumen fluid was obtained from all heifers via esophogeal tubing using a stainless-steel speculum and a stomach tube (1.91-cm OD, 1.27-cm ID, 3-m length) connected to a vacuum pump. Between heifers, the stomach tube was rinsed with water. The speculum was inserted into the mouth and guided into the esophagus, after which the tube was advanced into the rumen. Approximately 250 mL of rumen fluid was first withdrawn and discarded to minimize saliva contamination, followed by collection of the sample. Immediately after collection, rumen fluid pH was recorded, and the sample was filtered through 2 layers of cheesecloth. For preservation, 28 mL of filtered rumen fluid was mixed with 7 mL 25% (w/v) metaphosphoric acid in a conical tube and stored at −20 °C until analysis.

Urine Collection

Urine and fecal samples were obtained from a subset of 8 heifers per treatment (n=32) that were randomly selected before sample collection began. Fresh midstream urine was collected during spontaneous urination or by gentle vulvar stimulation while animals were restrained in a squeeze chute. Each sample was divided equally into two pre-labeled 15-mL conical tubes. One aliquot of 9 mL urine was acidified with 1 mL 1.8 M sulfuric acid, and a second aliquot was stored unacidified. Acidified samples were stored at −20 °C, and unacidified samples were stored at −80 °C until analysis. Fecal samples were obtained during spontaneous defecation when possible. If defecation did not occur, a gloved hand was inserted into the rectum to gently stimulate defecation and retrieve fecal material directly. Samples were transferred to pre-labeled aluminum pans and stored on ice until drying and initial processing.

Laboratory Analyses

Feed ingredients, diet samples, and fecal samples were dried in a forced-air oven at 55 °C for 48 h, allowed to air equilibrate for 24 h, and ground through a 1-mm screen using a Wiley mill (Thomas Scientific, Swedesboro, NJ). Dry matter content was determined by drying ground samples at 105 °C overnight in a forced-air oven. Organic matter content was determined as weight loss following combustion at 450 °C for 8 h in a muffle furnace. Gross energy concentration of composite treatment diet samples and alfalfa pellets was determined by bomb calorimetry using a bomb calorimeter. Total nitrogen content was measured using a TruMac N Analyzer (LECO Corporation, St. Joseph, MI). Indigestible NDF content in diet, ingredient, and fecal samples was determined using the ANKOM system (ANKOM Technology, Macedon, NY). Ground samples (0.5 g) were weighed into ANKOM F57 filter bags and heat sealed. Feed samples were subjected to a pepsin–HCl predigestion (0.1% pepsin in 0.1 M HCl) for 24 h at 39 °C prior to ruminal incubation, whereas fecal samples were analyzed without the acid-pepsin pretreatment (Beck et al., 2024). Individual filter bags were placed in mesh bags and incubated for 120 h in the rumen of cannulated dairy cow. After incubation, bags were removed, rinsed, dried at 55 °C, and analyzed for neutral detergent fiber (Van Soest et al., 1991) using an ANKOM Fiber Analyzer.

Acidified rumen fluid samples were centrifuged at 15,000 × *g* for 15 min at 4 °C to remove solid particles, and the clear liquid portion was filtered through a 0.45-μm filter and divided for analysis. For GC analysis, 0.3 mL of rumen fluid was combined with 0.9 mL of pivalic acid-containing solution (Czerkawski, 1976) as an internal standard and transferred to a 2-mL gas chromatography vial for volatile fatty acid analysis. Volatile fatty acids were analyzed using an Agilent 7890A gas chromatograph (Agilent Technologies Inc., Santa Clara, CA) equipped with a flame ionization detector. Separation was achieved using a DB-FFAP UI capillary column (30 m × 0.25 mm i.d. × 0.25 μm film thickness). The oven temperature was initially held at 130 °C for 5 min, increased at 30 °C/min to 250 °C, and held for 6 min. Samples were injected (0.2 μL) using a 20:1 split ratio with an injector temperature of 250 °C. Helium carrier gas flow was maintained at 1.2 mL/min. The flame ionization detector was operated at 250 °C with hydrogen and air flows of 35 and 400 mL/min, respectively. Acidified rumen fluid sample aliquots were analyzed colorimetrically for ammonia concentrations (Broderick and Kang, 1980) using a BioTek PowerWave XS microplate reader (BioTek Instruments, Winooski, VT).

Unacidified urine samples were thawed and analyzed for creatinine using a colorimetric assay kit (Cayman Chemical Company, Ann Arbor, MI). Urine samples were diluted 20:1 with distilled water prior to analysis as recommended by the manufacturer. Creatinine concentrations were calculated according to the manufacturer's instructions using the provided standard curve (0 to 150 mg/L) with a lower limit of quantification of 5 mg/L. Acidified urine samples were thawed and analyzed for N using a TruMac N Analyzer (LECO Corporation, St. Joseph, MI).

Weather Data

Daily weather data were obtained from the Kansas State University Mesonet weather station nearest to the research facility. Variables included mean, maximum, and minimum temperature; mean, maximum, and minimum relative humidity; mean and maximum wind speed; mean and maximum solar radiation; and daily precipitation. Dew point was calculated from daily temperature and relative humidity. Weather variables were summarized as means across the overall study and within each period.

Data Analysis

Statistical Analysis

All statistical analyses were conducted in SAS (version 9.4; SAS Institute Inc., Cary, NC). Data were analyzed as a completely randomized design with individual heifer as the experimental unit. Orthogonal polynomial contrasts were used to evaluate linear, quadratic, and cubic responses. Least squares means were generated for all response variables. Observations with studentized residuals > 4 were identified as outliers and removed from the data set. Results are presented as least squares means with the largest standard error of the mean among treatments. Significance was declared at $P \leq 0.05$ and tendencies as $0.05 < P \leq 0.10$.

Growth Performance

Initial and final body weights (BW) were defined as the means of BW measured on d 0 and 1 and on d 105 and 106, respectively. Average daily gain was calculated using two approaches. Regression-based ADG was estimated as the slope from a linear regression of body weight on study day for each heifer. Calculated ADG was determined from observed body weight change divided by days on feed. Total gain was calculated as final BW minus initial BW. Gain:feed was calculated as ADG divided by DMI. Total DMI was calculated as the sum of diet DMI plus pellet DMI from the AHCS.

Carcass Characteristics

Carcass characteristics were analyzed as a completely randomized design using PROC MIXED with treatment as a fixed effect and heifer as experimental unit. Carcass grade distributions were analyzed using PROC GLIMMIX with a binomial distribution and logit link. Fisher's exact tests were used because categorical counts had small numbers of observations.

Meal Feeding Behavior

Feeding behavior variables were calculated from Insentec visit records following aggregation of individual bunk visits into meals (Brown et al., 2022). Daily DMI was compared to the visit level DMI, and heifer days with a difference of > 0.5 kg were excluded before meal construction (3.6% of heifer days excluded). Visits were ordered chronologically by day within heifer, and meals crossing midnight were described as occurring on the preceding day. Meals were defined based on the interval between consecutive visits using a meal criterion of 16.7 min, where visits within 16.7 min were considered part of the same meal and those separated by > 16.7 min were considered separate meals; the 16.7 min threshold was derived from the distribution of intervals between heifer feed bunk visits. Intake associated with each visit was obtained from the Insentec system and used to calculate meal level intake. Daily summaries of feeding behavior variables were generated for each heifer and averaged within period as well as across the entire study for statistical analysis.

Overall and period means were analyzed separately using PROC MIXED. Baseline-adjusted models included the d -7 to 0 baseline value of the corresponding behavior trait as a covariate. Repeated-period model used ANTE(1) covariance structures. Behavior-weather models included treatment, time, and relevant weather covariates. Denominator degrees of freedom were adjusted using the Kenward-Roger method.

Methane Emissions

AHCS gas measurements recorded from individual visits were aggregated to estimate daily CH_4 production for each animal (Gunter and Beck, 2018). For data analysis, only visits longer than 3 min and with average airflow greater than 26 L/s were retained (Velazco et al., 2016). Approximately 28 to 30 AHCS visits per animal are recommended to yield good reliability (Beck et al., 2024). For our analyses, data from all heifers were used regardless of visit number with differences in estimate precision being accounted for during statistical analysis as described by Beck et al. (2025). Insufficient observations were available from the pre-trial baseline AHCS measurements and thus were not included as covariates in the statistical analyses of CH_4 emission.

GreenFeed data at the visit level were analyzed using PROC MIXED following Beck et al. (2025). Heifer was included as a fixed effect to obtain animal-level least squares means. Airflow and visit duration were evaluated as covariates and retained when $P \leq 0.10$. Three random-effect structures were evaluated for CH_4 production: (1) day and hour with interactions between hour and heifer, (2) model including day and hour as fixed effects, and (3) models including day, hour, and interactions of both day and hour with heifer as fixed effects. The final model included day, hour, day × heifer, and hour × heifer as random effects and was selected based on the lowest AIC and BIC values. Heifer level least squares means and associated standard errors were extracted from each model. Weighting factors were calculated as the inverse of the squared standard error ($1/SE^2$) to account for differences in estimate precision among heifers (Beck et al., 2025). Methane production (g/d) was calculated from AHCS mass flux measurements. Methane yield was determined as g CH_4/kg DMI, and methane intensity was calculated as g CH_4/kg ADG. Methane conversion factor (MJ/d) was calculated using 55.65 kJ/g

CH_4, then Ym % was calculated as methane energy loss divided by GE intake and expressed as a percentage.

Volatile Fatty Acids

Individual ruminal VFA concentrations included acetate, propionate, isobutyrate, butyrate, isovalerate, valerate, and caproate. Total VFA concentration (mM) was calculated as the sum of individual concentrations, and the molar acetate:propionate ratio was calculated from the individual values. Molar percentages were derived for each VFA as a proportion of total VFA. Volatile fatty acid variables were analyzed using repeated-measures PROC MIXED with treatment, collection day, and treatment × day as fixed effects and heifer as the subject. Baseline-adjusted models included the corresponding d 0 value as a covariate when applicable. Covariance structures, including ANTE(1) and SP(POW), were evaluated using AIC and BIC, and the final covariance structure was selected based on best model fit.

Nitrogen intake and excretion

Nitrogen intake was calculated using the analyzed N concentration of individual feed ingredients and their inclusion rates in the diet mixed for each collection day. Individual feed intake from the day prior to collection was obtained from the Insentec system, and N intake from alfalfa pellets consumed through the AHCS was also included. Total N intake was calculated from the N concentration and amount consumed from both the basal diet and AHCS pellets. Urinary excretion rate was estimated from urinary creatinine concentrations, assuming urinary creatinine excretion was 29 mg/kg BW daily (Lee et al., 2019). Urinary N excretion was calculated as urinary excretion rate × urine N concentration. Fecal output was estimated using indigestible NDF as an indigestible internal marker, and fecal N excretion was calculated as fecal output × fecal N concentration. Total N excretion was the sum of urinary and fecal N, and N retention was calculated as N intake − total N excretion.

Nitrogen variables were analyzed using repeated measures PROC MIXED with treatment, collection day, and treatment × day as fixed effects. Covariance structures, including SP(POW) and ANTE(1), were evaluated based on model fit with ANTE(1) being a better fit for these data based on the AIC and BIC.

Results

Performance

Growth performance and carcass data are presented in Table 3. Initial and final BW were not affected by treatment (P ≥ 0.680), but total gain and calculated ADG decreased linearly with increasing DynOmik supplementation (linear, P = 0.020). DMI was increased by 2.5 g/d but decreased by greater inclusion amounts (linear, P < 0.001; cubic, P = 0.005). Overall gain:feed ratio was not affected by treatment (P ≥ 0.330). Performance-based dietary NE_m demonstrated a quadratic response to CNSE supplementation (*P* = 0.050), whereas tendencies for quadratic responses were observed for NE_g and ME (*P* = 0.060); the quadratic effects were all a result of lower values for 2.5 g/d than for the other 3 treatments.

Empty body fat percentage, fat thickness, rib eye area, hot carcass weight, dressing percentage, marbling score, and calculated yield grade were not affected by DynOmik supplementation (*P* ≥ 0.490). USDA Quality grade distribution was not affected by treatment (Fisher's exact *P* = 0.330); however, quadratic tendencies were observed for the proportion of carcasses grading Prime (quadratic, *P* = 0.060) and Choice (quadratic, *P* = 0.070). Prime carcasses were lower for intermediate inclusion rates compared with control and 7.5 g/d, whereas Choice carcasses showed the opposite pattern. USDA Yield grade distribution was not affected by treatment (Fisher's exact *P* = 0.790), and no treatment effects were detected for the proportion of carcasses within individual yield grades (*P* ≥ 0.320).

Feeding Behavior

Feeding behavior data are presented in Table 4. The number of meals per day linearly increased with DynOmik supplementation (linear, $P = 0.03$), from 6.96 meals/d for controls to 7.38 meals/d for 7.5 g/d. Meal size increased above control for 2.5 g/d but declined for greater inclusion rates (linear, $P = 0.001$; cubic, $P = 0.001$). Maximum meal size followed a similar pattern, with the greatest numerical value at 2.5 g/d and lesser values at greater inclusion rates (linear, $P = 0.001$; cubic, $P = 0.02$). There was no detectable treatment effect on minimum meal size ($P = 0.40$). Meal duration and total daily meal duration demonstrated quadratic responses (P = 0.01), being greatest at 2.5 g/d. Eating time per meal and total eating time increased at 2.5 g/d and then decreased at greater inclusion rates (quadratic, $P < 0.0001$); total eating time also tended to exhibit a similar response (quadratic, $P < 0.0001$). Night visits to the bunk increased linearly ($P = 0.02$) with DynOmik supplementation. Visits per meal and day visits were not affected by treatment ($P \geq 0.15$).

Methane Emissions

Methane emission data are presented in Table 5. DynOmik supplementation did not result in a detectable difference in absolute methane production ($P = 0.257$), with overall means of 187.4, 178.5, 176.5, and 173.3 g/d for 0, 2.5, 5, and 7.5 g/d, respectively. Carbon dioxide emissions were also not influenced by treatment ($P = 0.413$), averaging approximately 11 kg/d across treatments. Methane yield (g/kg DMI) tended to be lower for 2.5 g/d than for other treatments (cubic, $P = 0.095$). Similar to methane yield, there was a tendency for Ym to be lower for 2.5 g/d than for the other treatments (cubic, $P = 0.077$). Methane intensity (g/kg calculated ADG) tended (cubic, $P = 0.092$), relative to control, to be reduced by 2.5 g/d, increased at 5 g/d, and unaffected by 7.5 g/d.

VFA

Rumen fluid pH and VFA and ammonia concentrations are presented in Table 6. Total VFA concentration was not affected by treatment ($P = 0.846$), and no treatment × day interaction was detected ($P = 0.542$). Similarly, molar percentages of acetate, propionate, isobutyrate, butyrate, isovalerate, and valerate, as well as the acetate-to-propionate ratio, were not affected by treatment ($P \geq 0.451$), and treatment × day interactions were not detected for these variables ($P \geq 0.442$). However, these variables generally differed by day, with day effects observed for total VFA ($P = 0.002$), acetate ($P < 0.001$), propionate ($P < 0.001$), isobutyrate ($P < 0.001$), and acetate-to-propionate ratio ($P < 0.001$), and tendencies for butyrate ($P = 0.099$) and valerate ($P = 0.057$). Caproate was the only VFA affected by treatment ($P = 0.006$), with linear ($P = 0.030$) and cubic ($P = 0.011$) responses across increasing DynOmik inclusion. Caproate peaked at 0.303% for 2.5 g/d relative to 0.246% for 0 g/d, and was reduced to 0.213% for both 5 and 7.5 g/d. Rumen fluid pH demonstrated a cubic effect ($P = 0.035$), reflecting a pattern in which mean pH increased from 6.71 at 0 g/d to 6.83 at 2.5 g/d, declined to 6.57 at 5 g/d, and returned to 6.85 at 7.5 g/d. A tendency for a day effect was observed ($P = 0.087$), with mean pH greatest on d 77, but no treatment × day interaction was detected ($P = 0.65$). Rumen ammonia concentration was not affected by treatment ($P \geq 0.20$), and no treatment × day interaction was detected ($P = 0.117$). Apparent DM and N digestibility were not affected by treatment ($P \geq 0.790$), and no treatment × day interactions were detected ($P \geq 0.240$). However, both DM and N digestibility differed by day ($P < 0.001$), with the greatest values observed on d 77.

Discussion

The central finding of this study was that DynOmik CNSE, a cold-extracted product containing at least 25% anacardic acid, did not improve feed efficiency in natural finishing heifers. However, the performance response appeared to be driven by intake, with DMI increasing at 2.5 g/d and decreasing at 5.0 and 7.5 g/d. ADG followed the same pattern as intake, with gain:feed being unaffected by treatment. Thus, the modest performance differences in this study are best explained by feed consumption and not by any change in metabolic efficiency from the additive.

The intake depression at higher doses of DynOmik was accompanied by changes in feeding behavior. Heifers supplemented with 5.0 or 7.5 g/d consumed smaller, more frequent meals than those receiving control or 2.5 g/d (Table 5). This pattern is more consistent with reduced diet acceptability than with a satiety or metabolic signal, because a satiety response would be expected to reduce meal size without increasing meal frequency (Allen et al., 2009), whereas the combination of smaller and more frequent meals suggests the animals were sampling and then rejecting the diet. This response is biologically plausible because anacardic acids can produce astringent and irritating sensory effects, with greater unsaturation of the aliphatic chain associated with increased perceived astringency (Brito et al., 2020). Differences in delivery method between our study and those of Cuervo et al. (2025) and Shinkai et al. (2012) may also help explain the observed intake response. Cuervo et al. (2025) fed 599-kg finishing steers CNSE at 5 g/d delivered separately from the basal diet through an automated feeding system with a corn gluten feed carrier and reported no negative effect on intake. Shinkai et al. (2012) fed 547-kg non-lactating Holstein cows CNSL at 4 g/100 kg of BW per day as pellets presented alongside the basal diet twice daily and observed no intake depression, although the first pellet formulation had poor palatability and was reformulated for a second trial. In both studies, the additive was offered separately from the basal diet, meaning that even if the supplement itself had reduced acceptability, intake of the rest of the diet would not be affected. In our study, CNSE was incorporated directly into the total mixed ration at concentrations ranging from 0.022 to 0.065% of DMI (0.005 to 0.015 g CNSE/kg BW), compared with approximately 0.038% of DMI (0.008 g/kg BW; Cuervo et al., 2025) and 0.31% of DMI (0.040 g/kg BW; Shinkai et al., 2012). Although our doses were similar to those of Cuervo et al. (2025) on both body weight and dietary concentration basis, the critical difference was delivery method. When CNSE is mixed into the TMR rather than offered as a separate supplement, heifers cannot selectively avoid it, and the palatability effects of the additive are expressed across the entire diet. The dose range that maintained intake was narrow, with only 2.5 g/d supporting greater DMI than control before intake declined at 5 and 7.5 g/d (Table 3). From a practical standpoint, mixing more than 0.022% of a CNSE product containing 25% anacardic acid with the diet may risk reductions in feed intake.

Anacardic acid content of CNSE varies widely based on extraction method, with cold extraction preserving anacardic acid and heat processing decarboxylating it to cardanol. DynOmik contained at least 25% anacardic acid, compared with 62.3% in the raw CNSL used by Watanabe et al. (2010), 78.16% in the product used by Saenab et al. (2017), and 59% in the granulated product used by Sarmikasoglou et al. (2024) and Goetz et al. (2023). The amount of supplemental anacardic acid might provide a better approach to compare among studies than the amount of product being fed.

Carcass data are presented in Table 3. The relatively large SEM for carcass measurements indicate limited power to detect small treatment effects. Hot carcass weight decreased numerically from control to 7.5 g/d, consistent with the reductions in DMI and ADG at higher doses, but dressing percentage was unaffected, indicating that the proportional relationship between live weight and carcass weight was maintained. There were no apparent effects of treatment on carcass quality; fat thickness, rib eye area, marbling score, yield grade, and quality grade distribution were all unaffected by treatment. The numerical differences in marbling score and the proportion of carcasses grading Choice or greater were more likely related to differences in feed intake than to a direct effect of CNSE on lipid metabolism or adipogenesis. Without a shift in fermentation profiles, there is no metabolic basis for expecting changes in carcass composition.

Feedlot cattle exhibit lower methane intensity compared to forage-fed animals. Thus, dietary composition likely influenced our results. The inclusion of distillers grains in our finishing ration introduced an additional methane-mitigating factor; Krogstad and Herrick (2026) noted that sulfate provided by distillers grains serves as an alternative hydrogen sink through sulfate reduction, potentially further reducing methanogenesis. Danielsson et al. (2014) observed an 18% in vitro reduction in methane using cold-extracted CNSE at 10 mg per 60 mL of rumen fluid with a 60:40 forage-to-concentrate diet, whereas Maeda et al. (2021) reported 20.2% to 23.4% reductions in vivo by feeding cold extracted CNSL at 4 to 6 g per 100 kg of body weight to beef cattle consuming a 60:40 rice straw-to-concentrate diet.

The argument that high-concentrate diets inherently constrain the ability to detect a propionate shift is difficult to sustain in light of the data of Cuervo et al. (2025), who supplemented Angus crossbred steers consuming an 85:15 grain:forage finishing ration with 5 g/d of the cold extracted CNSE from SDS Biotech (59% anacardic acid), delivering approximately 3.0 g of anacardic acid per day or roughly 250 mg/kg of dietary DM. Cuervo et al. (2025) observed a 22% increase in propionate concentration, a reduced acetate-to-propionate ratio, and a 28% reduction in in vivo methane emissions. This result demonstrates that a propionate shift is achievable on a high-grain diet when anacardic acid delivery is sufficient. The contrast between Cuervo et al. (2025) and our study might be explained by the approximately

40% greater amounts of dietary anacardic acid in their trial compared to our highest treatment. This suggests that providing CNSE supplementation as part of the mixed ration in the amount observed by Cuervo et al. (2025) may be sufficient at reducing methane, but it could lead to a reduction in feed intake.

The duration of the trial also distinguishes our results from shorter-term literature. Most published CNSL and CNSE feeding trials ranged from 21 to 56 d, including 21-d treatment periods with cold extract CNSL at 30 g per cow per day in lactating dairy cows (Branco et al., 2015) and 3-wk supplementation periods with raw CNSL pellets at 4 g per 100 kg of BW in non-lactating Holstein cows (Shinkai et al., 2012), up to 56-d crossover periods with cold-extracted CNSE at 5 g per steer per day in high-grain-fed beef steers (Cuervo et al., 2025). Our 105-d trial length allowed for potential microbial adaptation to the bioactive compounds. This is supported by Narabe et al. (2021) who reported that adding CNSL directly to fresh feces resulted in only a tendency for reduced methane production from Thai native cattle during a 24-h batch-culture assay. In contrast, methane production from swamp buffalo feces was reduced by 22% immediately after CNSL addition and by 16% after 30 d of fecal incubation, but the effect was no longer significant after 150 d. The authors attributed the strongest mitigation to the initial period of exposure, after which shifts in fecal bacterial and archaeal communities attenuated the response. These temporal patterns in vitro are consistent with our in vivo observation that CNSE supplementation did not produce a detectable methane reduction over 105 d, suggesting that microbial populations may have adapted to the bioactive compounds present in DynOmik well before the end of the study.

Mean ruminal pH in grain-adapted feedlot cattle is generally above 5.5, often in the range of 5.8 to 6.5 (Nagaraja and Titgemeyer, 2007). In the present study, ruminal pH was measured via esophageal tubing, which introduces the potential for saliva contamination given that mixed ruminant saliva has a pH of approximately 8.4 and contains high concentrations of bicarbonate and phosphate buffers (NASEM, 2016). Our pH readings were greater than those from typical spot-samples reported for feedlot cattle consuming high-concentrate diets, which likely reflects some degree of salivary contamination inherent to the sampling method. The absence of a measurable treatment effect on pH should therefore be interpreted cautiously.

Several factors likely contributed to the absence of detectable treatment differences in VFA concentrations and profiles. The most relevant comparison is the dietary concentration of anacardic acid. At the highest inclusion rate (7.5 g/d DynOmik, at least 25% anacardic acid), our heifers consumed approximately 1.9 g of anacardic acid per day or about 175 mg anacardic acid/kg of dietary DM. To compare the in vitro studies on a common basis, reported product doses were converted to anacardic acid doses. Watanabe et al. (2010) used raw CNSL at 25,000 mg product/kg substrate in batch culture and 13,333 mg product/kg substrate in the Rusitec system, corresponding to 15,575 and 8,307 mg anacardic acid/kg substrate, respectively, based on the reported 62.3% anacardic acid concentration. Sarmikasoglou et al. (2023) evaluated 100 and 200 mg granulated CNSE/kg substrate, equivalent to 59 and 118 mg anacardic acid/kg substrate, whereas Compton et al. (2023) evaluated 100 to 300 mg granulated CNSE/kg substrate, equivalent to 59 to 177 mg anacardic acid/kg substrate. Sarmikasoglou et al. (2024) observed no changes in VFA molar proportions or concentrations. Similarly, Compton et al. (2023) found no effect on VFA profile or digestibility with the same product at 100 to 300 mg/kg substrate. Thus, the anacardic acid concentration achieved in the present study was similar to concentrations that failed to alter VFA profiles in other *in vitro* studies and substantially lower than concentrations associated with large fermentation responses in Watanabe et al. (2010), suggesting that both the amount delivered and the persistence of bioactive anacardic acid in the rumen may influence the response.

The fate of anacardic acid in ruminal fluid also warrants consideration. Saenab et al. (2017) isolated anacardic acid to 99.44% purity from a Biofat product containing 78.16% anacardic acid in the crude extract and tracked its degradation in in vitro rumen incubations using thin-layer chromatography and gas chromatography-mass spectrometry. Thin-layer chromatography showed that the anacardic acid spot remained clearly visible at 12 h of incubation, thinned considerably by 24 h, and disappeared entirely by 48 h. Gas chromatography-mass spectrometry confirmed that the unsaturated alkyl side chains of anacardic acid were progressively hydrogenated to saturated forms beginning at 12 h, indicating active microbial modification of the bioactive molecule. Because cattle consume multiple meals per day, anacardic acid is continuously introduced, hydrogenated, and degraded while fresh material enters the rumen. The relevant metric is therefore not a single degradation time point but rather the steady-state concentration of bioactive, unhydrogenated anacardic acid in the rumen, which must remain above the threshold required to inhibit gram-positive bacteria. At the dietary concentrations achieved in our study, and considering ruminal retention times of 16 to 20 h in finishing cattle (Seo et al., 2006), the steady-state concentration of bioactive anacardic acid likely remained insufficient to produce a measurable fermentation shift. Together, the absence of a propionate response at dietary anacardic acid concentrations comparable to those tested in vitro (Sarmikasoglou et al., 2024; Compton et al., 2023), the positive response achieved at higher delivery rates on a similar high-grain diet (Cuervo et al., 2025), and the limited persistence of the bioactive molecule in ruminal fluid indicate that the expected fermentation shift did not materialize because anacardic acid delivery was below the effective threshold, not because high-concentrate diets preclude propionate enhancement.

The natural production system we utilized requires some context. Our heifers received no ionophores, implants, or beta-agonists, which distinguishes this study from conventional feedlot systems. Monensin shares CNSE's general mechanism of gram-positive selective inhibition (Russell and Strobel, 1989), and Beck et al. (2026) observed that including monensin in their in vitro substrate attenuated the methane-reducing effect of CNSL relative to studies conducted without it, suggesting overlapping activity. In our monensin-free system, CNSE failed to produce a detectable response, reinforcing that anacardic acid delivery, rather than the absence of an ionophore, was the primary constraint on efficacy.

The use of heifers rather than steers or non-lactating cows may have further modified the dose-response relationship. Breed composition and biological type can alter absolute methane production primarily through differences in dry matter intake rather than inherent differences in methanogenesis (Maciel et al., 2019), and heifers deposit more energy per unit of weight gain than steers, reaching mature body composition at a smaller body weight (Lofgreen and Garrett, 1968). This is reflected in the discrepancy between our formulated and performance-based dietary net energy values: based on chemical composition, dietary NEm and NEg were 1.88 and 1.25 Mcal/kg, respectively, whereas performance-based estimates calculated from observed intake and carcass data (Guiroy, 2001) yielded values of 1.52 to 1.64 Mcal/kg for NEm and 0.92 to 1.03 Mcal/kg for NEg, approximately 15 and 21% lower than estimates from chemical composition. However, these heifer-specific energetic differences do not override the more fundamental limitation: dietary anacardic acid delivery at 175 mg/kg DM fell below the threshold at which Cuervo et al. (2025) achieved a propionate shift and methane reduction on a comparable high-grain diet.

In this 105-d finishing trial, CNSE did not significantly reduce absolute CH_4 production; however, a small methane response cannot be excluded. Methane yield and Ym tended to be lower at 2.5 g/d, and methane intensity showed a similar numerical response. These changes were small, occurred alongside differences in DMI, and were not accompanied by shifts in VFA profiles. Therefore, the magnitude of CH_4 mitigation reported in previous studies was not achieved in the present study, although minor effects at lower CNSE inclusion rates cannot be ruled out. Although previous literature suggests that CNSE can redirect metabolic H_2 toward propionate, the amount of anacardic acid delivered in the present study may have been insufficient to produce a measurable fermentation response, particularly compared with the substantially greater anacardic acid concentrations associated with responses in Watanabe et al. (2010). Our highest inclusion rate provided approximately 175 mg of anacardic acid/kg of dietary DM. Greater CNSE inclusion may increase anacardic acid delivery, but the reductions in DMI and ADG observed at 5.0 and 7.5 g/d suggest that higher inclusion rates could also negatively affect diet acceptability and animal performance.

Future research should focus on identifying the precise anacardic acid delivery threshold required for high-grain diets and evaluating more granular dosage steps. Responses to CNSE were characterized more by changes in intake and meal behavior than by shifts in ruminal fermentation or reductions in CH_4 production. The 2.5 g/d dose maintained ADG comparable to the control and produced distinct responses in meal size and eating duration, whereas greater doses reduced DMI and ADG. These results suggest that lower doses and alternative formulations that minimize potential palatability effects warrant further evaluation in natural finishing cattle.

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Table 1. Composition of diet fed to natural finishing heifers

Item	Control diet[1]	Alfalfa pellets
Ingredient	% of dry matter	
Silage	22.8	-
Distillers grains	19.5	-
Dry-rolled Corn	54.5	-
Premix[2]	3.2	-
Alfalfa pellets	-	100
Nutrient composition (dry matter basis unless otherwise specified)		
Dry matter, % as is	66.7	93.2
Crude protein, %	13.2	21.0
Soluble protein, % of crude protein	23.5	30.0
Acid detergent fiber, %	8.2	37.1
Neutral detergent fiber, %[3]	17.1	49.4
Indigestible neutral detergent fiber, %[4]	4.5	27.2
Total digestible nutrients, %[5]	76.8	57.0
Gross energy, MJ/kg	18.4	18.5
Net energy for maintenance, Mcal/kg[6]	1.88	1.14
Net energy for gain, Mcal/kg[6]	1.25	0.58

[1]Basal diet composition was common across treatments. Cattle received 0, 2.5, 5.0, or 7.5 g CNSE/heifer daily by adding increasing amounts of CNSE to the same base mix.

[2]Premix nutrient specifications (as-fed basis) were 20.00 to 21.00% calcium, 9.25 to 9.50% salt, 0.38% potassium, 1.20% magnesium, 1.00% sulfur, 83,350 IU/kg vitamin A, 8,335 IU/kg vitamin D, 282 IU/kg vitamin E, 1,900 ppm zinc, 1,250 ppm manganese, 300 ppm copper, 32 ppm iodine, 6.6 ppm cobalt, and 8 ppm selenium.

[3]Analyzed with α-amylase and sodium sulfite and expressed inclusive of residual ash.

[4]Determined after 120 h of ruminal incubation as described in methods.

[5]Calculated by Dairy One using NRC (2001; Nutrient Requirements of Dairy Cattle, 7th rev. ed.) summative equations from analyzed nutrient fractions including NFC, CP, fatty acids, and NDF.

[6] NE_m and NEg were derived by Dairy One from calculated TDN using NRC (2000; Nutrient Requirements of Beef Cattle, 7th rev. ed., Update 2000) energy conversion equations.

Table 2. Summary of ambient weather conditions across the entire feeding period

Item[2]	Overall	Day 1 to 42	Day 42 to 77	Day 77 to 106
Mean temperature, °C	25.00	27.13	24.52	22.68
Maximum temperature, °C	28.89	31.29	27.97	26.60
Minimum temperature, °C	20.03	22.65	19.57	17.20
Mean dew point, °C[1]	17.31	19.68	16.64	14.77
Maximum dew point, °C[1]	25.56	27.43	24.76	23.60
Minimum dew point, °C[1]	8.34	11.20	8.07	4.93
Mean wind speed, m/s	2.03	2.20	1.95	1.90
Maximum wind speed, m/s	3.03	3.25	2.79	2.99
Mean solar radiation, W/m^2	365	414	356	318
Maximum solar radiation, W/m^2	679	774	647	586
Precipitation, mm/d	3.41	2.94	2.22	5.32

[1]Dew point was calculated from daily temperature and relative humidity.
[2]Values reported as means within period

Table 3. Effects of cashew nut shell extract supplementation on growth performance and carcass characteristics of natural finishing heifers

	DynOmik, g/d					P-value			
Item	0	2.5	5	7.5	SEM	Trt	Linear	Quadratic	Cubic
Body weight, kg									
Initial (average of d 0 and 1)	516.6	511.5	520.3	513.1	9.3	0.913	0.967	0.912	0.477
Day 42	581.9	587.6	578.1	582.1	10.6	0.937	0.848	0.937	0.545
Day 77	620.0	616.7	610.8	606.7	10.7	0.821	0.345	0.965	0.929
Final (average of d 105 and 106)	654.4	652.2	643.4	635.9	12	0.68	0.234	0.827	0.885
Total gain, kg									
Overall	137.8	140.7	123.1	122.8	5.8	0.059	0.020	0.785	0.156
Day 1-42	65.3	76.1	61.0	69.0	5.1	0.188	0.856	0.782	0.032
Day 42-77	38.0	29.2	30.8	24.6	4.1	0.119	0.031	0.74	0.307
Day 77-106	34.5	35.5	32.5	29.2	3.2	0.521	0.191	0.499	0.806
Average daily gain, kg/d									
Overall	1.31	1.34	1.17	1.17	0.056	0.059	0.020	0.785	0.156
Day 1-42	1.59	1.86	1.49	1.68	0.12	0.188	0.856	0.782	0.032
Day 42-77	1.09	0.83	0.88	0.70	0.12	0.119	0.031	0.740	0.307
Day 77-106	1.19	1.22	1.12	1.01	0.11	0.521	0.191	0.499	0.806
Dry matter intake, kg/d									
Overall	11.86	12.64	11.00	10.72	0.29	<0.001	<0.001	0.071	0.005
Day 1-42	11.86	12.59	11.60	11.14	0.29	0.007	0.018	0.044	0.083
Day 42-77	12.16	13.10	11.08	10.77	0.33	<0.001	<0.001	0.066	0.003
Day 77-106	11.47	12.14	9.96	10.00	0.34	<0.001	<0.001	0.357	0.001
Gain:feed, kg/kg									
Overall	0.111	0.106	0.106	0.110	0.004	0.799	0.839	0.330	0.957
Day 1-42	0.133	0.148	0.126	0.152	0.01	0.188	0.42	0.539	0.052
Day 42-77	0.090	0.064	0.079	0.066	0.01	0.239	0.208	0.507	0.144
Day 77-106	0.104	0.101	0.110	0.100	0.01	0.913	0.970	0.753	0.519
NEm required, Mcal/d	8.89	8.84	8.84	8.76	0.12	0.886	0.457	0.859	0.820
NEg,required Mcal/d	6.20	6.20	5.43	5.46	0.26	0.049	0.013	0.961	0.184
Performance-based dietary net energy[2]									
Net energy for maintenance, Mcal/kg	1.595	1.516	1.597	1.637	0.030	0.049	0.135	0.054	0.147
Net energy for gain, Mcal/kg	0.989	0.919	0.992	1.025	0.027	0.050	0.135	0.061	0.132
Metabolizable energy, Mcal/kg	2.489	2.400	2.492	2.539	0.035	0.051	0.130	0.056	0.152
Carcass									
Empty body fat, %	28.6	27.9	27.7	28.2	0.54	0.68	0.58	0.27	1.00
12^{th} rib fat thickness, cm	0.85	0.81	0.74	0.85	0.068	0.66	0.86	0.29	0.53
Rib eye area, cm²	95.4	93.7	96.4	91.8	2.8	0.67	0.52	0.6	0.36
Hot carcass weight, kg	404.1	402.5	399.1	396.2	11	0.91	0.46	0.95	0.96

Dressing, %	64.3	64.3	64.6	64.9	0.46	0.72	0.30	0.69	0.80
Marbling score[3]	631	590	577	626	31	0.54	0.84	0.15	0.82
Prime, %[4]	27	7	7	27	11.4	0.30	1.00	0.06	1.00
Choice, %[4]	73	93	87	67	12.2	0.31	0.53	0.07	0.62
Select, %[4]	0	0	7	7	6.4	1.00	0.98	1.00	0.99
Calculated yield grade	3.33	3.27	2.87	3.40	0.27	0.49	0.87	0.26	0.29
Yield grade 1, %[5]	7	7	7	7	6.4	1.00	1.00	1.00	1.00
Yield grade 2, %[5]	13	7	13	13	8.8	0.93	0.83	0.65	0.57
Yield grade 3, %[5]	40	47	67	33	12	0.32	0.99	0.13	0.25
Yield grade 4, %[5]	20	33	13	27	12	0.62	0.98	0.90	0.19
Yield grade 5, %[5]	20	7	0	20	10	0.75	0.97	0.97	0.97

[1]Largest standard error of the mean among treatments.
[2]Performance-based dietary net energy values were estimated from observed individual animal performance and carcass data using the iterative quadratic solution of the California Net Energy System as described by Guiroy (2001) and NASEM (2016).
[3]Marbling scores correspond to USDA marbling categories. 500 = Modest, mid-Choice. 600 = Moderate, upper Choice.
[4]Quality grade distribution was analyzed using Fisher's exact test; P = 0.33.
[5]Yield grade distribution was analyzed using Fisher's exact test; P = 0.79

Table 4. Effects of cashew nut shell extract supplementation on feeding behavior of natural finishing heifers

	DynOmik, g/d					*P*-value					
Item[2]	0	2.5	5	7.5	SEM[1]	Trt	Day	Trt × Day	Linear	Quadratic	Cubic
Meals, d^{-1}											
Overall	6.96	6.95	7.11	7.38	0.18	0.15	<.0001	0.27	0.03	0.35	0.94
Day 1-42	7.84	7.78	7.86	8.33							
Day 42-77	6.58	6.60	6.98	7.04							
Day 77-106	6.45	6.48	6.49	6.76							
Meal size, kg/meal											
Overall	1.74	1.85	1.57	1.59	0.06	<.0001	<.0001	<.0001	0.001	0.34	0.001
Day 1-42	1.55	1.67	1.52	1.47							
Day 42-77	1.88	2.01	1.61	1.66							
Day 77-106	1.80	1.87	1.58	1.64							
Maximum meal size, kg											
Overall	3.21	3.31	2.92	2.93	0.10	0.001	<.0001	0.12	0.001	0.55	0.02
Day 1-42	3.02	3.17	2.91	2.72							
Day 42-77	3.37	3.45	2.96	3.09							
Day 77-106	3.23	3.32	2.88	2.98							
Minimum meal size, kg											
Overall	0.63	0.64	0.60	0.57	0.04	0.40	<.0001	0.001	0.12	0.63	0.64

Day 1-42	0.51	0.51	0.56	0.53							
Day 42-77	0.73	0.73	0.62	0.60							
Day 77-106	0.67	0.69	0.61	0.59							
Meal duration, min/meal											
Overall	17.14	19.09	18.01	16.47	0.85	0.04	0.01	0.07	0.31	0.01	0.39
Day 1-42	16.60	17.99	17.76	15.64							
Day 42-77	17.58	20.46	17.84	16.43							
Day 77-106	17.25	18.81	18.45	17.33							
Total duration, min/d											
Overall	114	129	121	113	5.38	0.03	<.0001	0.31	0.59	0.01	0.18
Day 1-42	125	134	131	121							
Day 42-77	110	132	118	109							
Day 77-106	107	120	113	111							
Eating time, min/meal											
Overall	11.88	14.85	12.95	9.80	0.82	<.0001	0.38	0.00	0.01	<.0001	0.20
Day 1-42	11.99	13.82	13.65	10.11							
Day 42-77	11.89	16.47	12.50	9.47							
Day 77-106	11.75	14.27	12.71	9.81							
Total eating time, min/d											
Overall	79	101	87	70	5.14	<.0001	<.0001	0.02	0.03	<.0001	0.06
Day 1-42	89	103	100	79							
Day 42-77	74	108	83	65							
Day 77-106	72	92	78	65							
Visits per meal											
Overall	3.98	3.66	3.78	4.00	0.26	0.51	0.00	0.36	0.82	0.15	0.70
Day 1-42	3.74	3.55	3.42	3.55							
Day 42-77	4.20	3.72	3.99	4.12							
Day 77-106	3.99	3.72	3.92	4.33							
Day visits, d^{-1}											
Overall	24.17	22.21	23.80	24.77	1.47	0.41	<.0001	0.39	0.50	0.19	0.41
Day 1-42	26.69	24.93	25.14	26.54							
Day 42-77	24.05	21.27	24.30	24.05							
Day 77-106	21.79	20.44	21.96	23.73							
Night visits, d^{-1}											
Overall	2.36	2.16	2.62	3.34	0.44	0.08	<.0001	0.06	0.02	0.19	0.78
Day 1-42	1.50	1.34	1.68	2.17							
Day 42-77	2.64	2.08	3.10	3.63							
Day 77-106	2.94	3.05	3.08	4.21							
Eating rate, g/min											
Overall	188	172	160	175	7.86	0.003	<.0001	0.03	0.03	0.00	0.31

Day 1-42	175	169	154	156
Day 42-77	196	174	163	184
Day 77-106	192	172	163	184

[1] Largest standard error of the mean

[2] Analyses included visit behavior the week prior to study as covariates.

Table 5. Effects of cashew nut shell extract supplementation on methane emissions of natural finishing heifers

	DynOmik, g/d					*P*-value			
Item	0	2.5	5	7.5	SEM	Trt	Linear	Quadratic	Cubic
Methane emission, g/d									
Overall	187.4	178.5	176.5	173.3	9.24	0.672	0.257	0.743	0.831
Day 1-42	193.4	197.6	188.1	166.7	12.71	0.305	0.107	0.284	0.972
Day 42-77	190.1	183.0	181.1	174.8	10.73	0.745	0.288	0.967	0.828
Day 77-106	176.2	162.0	159.8	166.4	9.93	0.544	0.442	0.256	0.935
Methane yield, g/kg DMI									
Overall	15.8	14.2	16.2	16.3	0.79	0.167	0.299	0.240	0.095
Day 1-42	16.4	15.6	16.5	15.4	1.04	0.827	0.635	0.906	0.409
Day 42-77	15.6	14.1	16.3	16.3	0.90	0.229	0.254	0.333	0.118
Day 77-106	15.4	13.5	16.2	16.6	1.07	0.127	0.155	0.243	0.112
Methane intensity, g/kg ADG									
Overall	144.5	135.9	158.1	145.3	9.4	0.336	0.531	0.813	0.092
Day 1-42 (average d 0/1)	110.1	113.2	116.1	102.8	10.7	0.828	0.690	0.427	0.724
Day 42-77	360.8	329.1	227.1	96.8	162.9	0.631	0.198	0.750	0.951
Day 77-106 (average d 105/106)	153.6	149.9	160.0	172.0	25.2	0.921	0.527	0.730	0.907
Methane energy loss, MJ/d									
Overall	10.43	9.94	9.82	9.64	0.5142	0.672	0.257	0.743	0.831
Day 1-42	10.76	11.00	10.47	9.28	0.7074	0.305	0.107	0.284	0.972
Day 42-77	10.58	10.18	10.08	9.73	0.5969	0.745	0.288	0.967	0.828
Day 77-106	9.80	9.01	8.89	9.26	0.5525	0.544	0.442	0.256	0.935
Ym, %									
Overall	5.14	4.60	5.30	5.33	0.259	0.130	0.246	0.241	0.077
Day 1-42	5.34	5.07	5.40	5.05	0.339	0.808	0.704	0.905	0.361
Day 42-77	5.09	4.56	5.34	5.34	0.294	0.186	0.212	0.335	0.099
Day 77-106	5.01	4.38	5.32	5.43	0.349	0.104	0.131	0.244	0.097
Methane CO_2 equivalent, g/d									
Overall	5,248	4,999	4,943	4,852	259	0.672	0.257	0.743	0.831
Day 1-42	5,414	5,534	5,268	4,668	356	0.305	0.107	0.284	0.972
Day 42-77	5,323	5,123	5,072	4,895	300	0.745	0.288	0.967	0.828
Day 77-106	4,933	4,535	4,474	4,658	278	0.544	0.442	0.256	0.935
CO_2 emission, g/d									
Overall	11,105	11,106	10,783	10,857	309	0.790	0.413	0.899	0.576
Day 1-42	10,157	10,529	10,038	9,872	348	0.536	0.377	0.418	0.411
Day 42-77	11,580	11,639	11,310	11,382	359	0.883	0.541	0.985	0.605

Day 77-106	11,162	10,994	10,710	10,832	305	0.661	0.316	0.605	0.675

[1] Largest standard error of the mean among treatments.

[4] Methane energy loss, MJ/d = methane, g/d × 0.05565.

[5] Ym, % = enteric methane, MJ/d / gross energy intake, MJ/d × 100.

[6] Methane CO_2 equivalent, g/d = methane, g/d × 28.

Table 6. Effects of cashew nut shell extract supplementation on apparent digestibility and ruminal fermentation characteristics of finishing heifers

	DynOmik, g/d					*P*-value					
Item	0	2.5	5	7.5	SEM[1]	TRT	Day	TRT x Day	Linear	Quadratic	Cubic
Nitrogen digestibility, g/g											
Overall	0.772	0.762	0.772	0.773	0.026	0.92	<0.001	0.56	0.78	0.67	0.6x
Day 42	0.760	0.771	0.776	0.768							
Day 77	0.818	0.809	0.800	0.797							
Day 105	0.737	0.708	0.741	0.755							
DM digestibility, g/g											
Overall	0.819	0.806	0.808	0.816	0.017	0.79	<0.001	0.24	0.83	0.33	0.86
Day 42	0.810	0.813	0.808	0.818							
Day 77	0.854	0.849	0.830	0.837							
Day 105	0.794	0.757	0.787	0.792							
Rumen fluid pH											
Overall	6.71	6.83	6.57	6.85	0.152	0.126	0.087	0.65x	0.66x	0.36x	0.035
Day 42	6.73	6.81	6.39	6.76							
Day 77	6.77	6.82	6.80	7.01							
Day 105	6.62	6.86	6.51	6.77							
Rumen ammonia, mM											
Overall	4.9	5.2	4.2	5.2	0.805	0.53	0.37	0.117	0.98x	0.47x	0.2xx
Day 42	4.3	5.2	3.6	5.2							
Day 77	5.8	4.1	4.1	5.5							
Day 105	4.7	6.2	5.0	5.0							
Acetate:propionate, mol/mol											
Overall	2.32	2.27	2.24	2.21	0.248	0.957	<.0001	0.945	0.581	0.962	0.986
Day 42	2.6	2.6	2.41	2.45							
Day 77	2.01	2.05	2.08	1.92							
Day 105	2.34	2.17	2.22	2.25							
Total VFA, mM											
Overall	184.5	182.7	193.5	187.0	17.15	0.846	0.002	0.542	0.654	0.795	0.464
Day 42	165.2	143.4	169.1	175.1							
Day 77	198.0	201.7	190.7	188.5							
Day 105	190.3	203.0	220.8	197.4							
Acetate, mol/100 mol total VFA											
Overall	56.8	57.2	56.1	56.3	1.39	0.848	<.0001	0.785	0.546	0.954	0.51x
Day 42	59.4	60.7	58.0	58.5							
Day 77	55.0	54.5	54.8	54.0							
Day 105	56.1	56.4	55.4	56.5							
Propionate, mol/100 mol total VFA											

Overall	27.4	27.2	28.3	28.0	2.01	0.908	<0.001	0.975	0.59x	0.952	0.62x
Day 42	25.2	25.1	27.2	26.4							
Day 77	28.9	29.2	29.2	30.0							
Day 105	28.0	27.4	28.6	27.6							
Isobutyrate, mol/100 mol total VFA											
Overall	1.14	1.08	1.08	1.15	0.09	0.606	<.0001	0.773	0.909	0.179	0.988
Day 42	1.10	0.93	0.91	0.99							
Day 77	1.28	1.19	1.25	1.34							
Day 105	1.05	1.10	1.07	1.12							
Butyrate, mol/100 mol total VFA											
Overall	10.3	9.7	10.2	10.3	0.93	0.871	0.099	0.971	0.826	0.569	0.56x
Day 42	10.2	8.6	9.6	9.5							
Day 77	10.4	10.0	10.4	10.6							
Day 105	10.2	10.4	10.6	10.8							
Isovalerate, mol/100 mol total VFA											
Overall	2.52	2.34	2.25	2.32	0.283	0.451	0.373	0.997	0.224	0.321	0.945
Day 42	2.37	2.19	2.20	2.23							
Day 77	2.49	2.29	2.25	2.36							
Day 105	2.70	2.52	2.32	2.35							
Valerate, mol/100 mol total VFA											
Overall	1.69	1.83	1.72	1.69	0.212	0.759	0.057	0.442	0.83x	0.404	0.497
Day 42	1.63	1.97	1.95	1.97							
Day 77	1.75	1.82	1.59	1.64							
Day 105	1.68	1.71	1.63	1.46							
Caproate, mol/100 mol total VFA											
Overall	0.25	0.30	0.21	0.21	0.039	0.006	<.0001	0.102	0.03	0.142	0.011
Day 42	0.27	0.39	0.26	0.29							
Day 77	0.28	0.36	0.21	0.21							
Day 105	0.19	0.16	0.17	0.14							

[1]Largest standard error of the mean among treatments.

Appendix Table 1. Growth performance responses of natural finishing heifers analyzed without a covariate and with initial or average body weight as covariates.

		DynOmik, g/d							*P*-value				
Variable	Cov	0	2.5	5	7.5	SEM	AIC	BIC	Cov	Trt	Linear	Quadratic	Cubic
Initial body weight day 1, kg													
Overall	.	526.66	519.34	526.84	519.28	9.257	572.6	574.7	.	0.88536	0.72501	0.98962	0.47349
Day 42	.	581.93	587.56	578.14	582.12	10.6294	574	576	.	0.93662	0.84777	0.93681	0.54474
Day 77	.	619.95	616.71	610.84	606.67	10.7352	589.2	591.3	.	0.82145	0.34532	0.96533	0.92855
Initial body weight averaged day 0 and day 1, kg													
Overall	.	516.59	511.49	520.25	513.09	9.2951	573.1	575.1	.	0.91258	0.96707	0.91232	0.47708
Final body weight day 106, kg													
Overall	.	649.21	648.97	640.55	631.09	12.1832	603.4	605.4	.	0.6865	0.25406	0.70681	0.89604
Day 42	.	581.93	587.56	578.14	582.12	10.6294	574	576	.	0.93662	0.84777	0.93681	0.54474
Day 77	.	619.95	616.71	610.84	606.67	10.7352	589.2	591.3	.	0.82145	0.34532	0.96533	0.92855
Final body weight averaged day 105 and day 106, kg													
Overall	.	654.42	652.16	643.37	635.85	11.988	601.6	603.6	.	0.68024	0.23417	0.82721	0.88452
Dry matter intake, kg/d													
Overall	.	11.8574	12.6438	10.9959	10.7208	0.2881	184	186	.	0.00005	0.00024	0.07068	0.00456
Day 1--42	.	11.8571	12.5891	11.5957	11.1432	0.2873	183.7	185.7	.	0.00722	0.01788	0.04392	0.08318
Day 42-77	.	12.1584	13.0966	11.0755	10.7673	0.3329	200.2	202.2	.	0.00002	0.00011	0.06645	0.00271
Day 77-106	.	11.4677	12.1418	9.9599	10.0033	0.3392	202.3	204.3	.	0.00002	0.00006	0.35652	0.00145
Overall	Initial BW	11.7232	12.4555	10.9339	11.1053	0.2602	168.4	170.4	<.0001	0.00029	0.00526	0.27161	0.00073
Day 1--42	Initial BW	11.7025	12.3721	11.5241	11.5863	0.2421	160.4	162.4	<.0001	0.04856	0.27289	0.20131	0.02155
Day 42-77	Initial BW	12.0421	12.9334	11.0217	11.1007	0.3254	192.9	194.9	0.0022	0.00016	0.0019	0.20363	0.001
Day 77-106	Initial BW	11.3421	11.9656	9.9018	10.3631	0.3277	193.7	195.7	0.0011	0.00008	0.00119	0.79969	0.00042
Overall	Average BW	11.7232	12.4555	10.9339	11.1053	0.2602	168.4	170.4	<.0001	0.00029	0.00526	0.27161	0.00073
Day 1--42	Average BW	11.7025	12.3721	11.5241	11.5863	0.2421	160.4	162.4	<.0001	0.04856	0.27289	0.20131	0.02155
Day 42-77	Average BW	12.0421	12.9334	11.0217	11.1007	0.3254	192.9	194.9	0.0022	0.00016	0.0019	0.20363	0.001
Day 77-106	Average BW	11.3421	11.9656	9.9018	10.3631	0.3277	193.7	195.7	0.0011	0.00008	0.00119	0.79969	0.00042
Total gain day 1 to day 106, kg													
Overall	.	122.56	129.63	113.71	111.81	6.5538	534	536	.	0.20253	0.10601	0.49658	0.2117
Day 1--42	.	55.2784	68.221	54.4316	62.8383	4.9972	491	493	.	0.15611	0.68264	0.64331	0.02981
Day 42-77	.	38.0114	29.1512	30.7798	24.5547	4.0503	467.9	469.9	.	0.11922	0.03129	0.73983	0.30671
Day 77-106	.	29.2659	32.2592	29.7015	24.42	3.6962	469.8	471.8	.	0.50792	0.30548	0.26777	0.86481
Overall	Initial BW	122.35	130.27	112.89	112.19	6.4428	533.7	535.7	0.0776	0.16155	0.10153	0.5049	0.15172
Day 1--42	Initial BW	55.2515	68.2606	54.3981	62.857	5.0451	494.4	496.4	0.8551	0.16023	0.68323	0.64525	0.03077
Day 42-77	Initial BW	37.8869	29.3344	30.6242	24.6412	4.0485	470.6	472.6	0.2941	0.13022	0.03246	0.74585	0.34048
Day 77-106	Initial BW	29.1356	32.6678	29.1841	24.6591	3.6042	469.8	471.8	0.0455	0.48132	0.29745	0.26741	0.71287
Overall	Average BW	121.18	128.71	114.09	113.72	5.7124	520.7	522.7	<.0001	0.21554	0.15388	0.49099	0.15862
Day 1--42	Average BW	55.2005	68.059	54.5163	62.9992	4.9442	492.4	494.4	0.1444	0.15409	0.64717	0.65165	0.02983

Day 42-77	Average BW	37.4623	28.8593	31.1529	25.0475	3.9507	468.2	470.2	0.0522	0.14914	0.04691	0.74669	0.2704
Day 77-106	Average BW	28.1683	31.5667	30.1636	25.748	3.3676	462.4	464.4	0.0006	0.63965	0.56973	0.24832	0.90535
Total gain using averaged day 0 and day 1 to averaged day 105 and day 106, kg													
Overall	.	137.83	140.67	123.12	122.76	5.8486	521.2	523.2	.	0.05884	0.01978	0.7853	0.15636
Day 1--42	.	65.3482	76.0682	61.0412	69.0223	5.0569	492.3	494.3	.	0.18776	0.8555	0.78218	0.03229
Day 77-106	.	34.4689	35.4505	32.5226	29.1835	3.1711	452.7	454.7	.	0.52139	0.1907	0.49851	0.80606
Overall	Initial BW	137.66	141.19	122.47	123.06	5.781	521.8	523.8	0.1125	0.04619	0.01865	0.80064	0.11443
Day 1--42	Initial BW	65.3949	75.9995	61.0995	68.9899	5.1022	495.6	497.6	0.7539	0.20253	0.8528	0.78584	0.03578
Day 77-106	Initial BW	34.3357	35.8684	31.9936	29.428	3.0422	451.2	453.2	0.0163	0.46777	0.17615	0.5024	0.62422
Overall	Average BW	136.54	139.81	123.48	124.55	4.9996	506	508	<.0001	0.05154	0.0233	0.8265	0.10276
Day 1--42	Average BW	65.2687	75.9028	61.1276	69.1866	5.0014	493.6	495.6	0.1408	0.18929	0.88955	0.79268	0.0323
Day 77-106	Average BW	33.4445	34.8042	32.954	30.423	2.8245	443.1	445.1	0.0002	0.74086	0.39409	0.49143	0.84116
Average daily gain calculated from day 1 to day 106, kg/d													
Overall	.	1.1672	1.2346	1.0829	1.0649	0.06242	12.7	14.8	.	0.20253	0.10601	0.49658	0.2117
Day 1--42	.	1.3483	1.6639	1.3276	1.5326	0.1219	82.5	84.5	.	0.15611	0.68264	0.64331	0.02981
Day 42-77	.	1.086	0.8329	0.8794	0.7016	0.1157	76.8	78.8	.	0.11922	0.03129	0.73983	0.30671
Day 77-106	.	1.0092	1.1124	1.0242	0.8421	0.1275	92.7	94.7	.	0.50792	0.30548	0.26777	0.86481
Overall	Initial BW	1.1652	1.2407	1.0752	1.0685	0.06136	21.8	23.8	0.0776	0.16155	0.10153	0.5049	0.15172
Day 1--42	Initial BW	1.3476	1.6649	1.3268	1.5331	0.1231	93.3	95.3	0.8551	0.16023	0.68323	0.64525	0.03077
Day 42-77	Initial BW	1.0825	0.8381	0.875	0.704	0.1157	86.7	88.6	0.2941	0.13022	0.03246	0.74585	0.34048
Day 77-106	Initial BW	1.0047	1.1265	1.0063	0.8503	0.1243	99.4	101.4	0.0455	0.48132	0.29745	0.26741	0.71287
Overall	Average BW	1.1541	1.2258	1.0866	1.083	0.0544	8.8	10.8	<.0001	0.21554	0.15388	0.49099	0.15862
Day 1--42	Average BW	1.3464	1.66	1.3297	1.5366	0.1206	91.3	93.3	0.1444	0.15409	0.64717	0.65165	0.02983
Day 42-77	Average BW	1.0704	0.8246	0.8901	0.7156	0.1129	84.3	86.2	0.0522	0.14914	0.04691	0.74669	0.2704
Day 77-106	Average BW	0.9713	1.0885	1.0401	0.8879	0.1161	92	94	0.0006	0.63965	0.56973	0.24832	0.90535
Average daily gain calculated using averaged day 0 and day 1 at the start and averaged day 105 and day 106 at the end, kg/d													
Overall	.	1.3127	1.3397	1.1726	1.1691	0.0557	0	2	.	0.05884	0.01978	0.7853	0.15636
Day 1--42	.	1.5939	1.8553	1.4888	1.6835	0.1233	83.8	85.8	.	0.18776	0.8555	0.78218	0.03229
Day 77-106	.	1.1886	1.2224	1.1215	1.0063	0.1093	75.5	77.5	.	0.52139	0.1907	0.49851	0.80606
Overall	Initial BW	1.3111	1.3446	1.1664	1.172	0.05506	9.8	11.9	0.1125	0.04619	0.01865	0.80064	0.11443
Day 1--42	Initial BW	1.595	1.8536	1.4902	1.6827	0.1244	94.5	96.5	0.7539	0.20253	0.8528	0.78584	0.03578
Day 77-106	Initial BW	1.184	1.2368	1.1032	1.0148	0.1049	80.8	82.8	0.0163	0.46777	0.17615	0.5024	0.62422
Overall	Average BW	1.3004	1.3315	1.176	1.1862	0.04761	-5.9	-3.9	<.0001	0.05154	0.0233	0.8265	0.10276
Day 1--42	Average BW	1.5919	1.8513	1.4909	1.6875	0.122	92.6	94.6	0.1408	0.18929	0.88955	0.79268	0.0323
Day 77-106	Average BW	1.1533	1.2001	1.1363	1.0491	0.0974	72.7	74.7	0.0002	0.74086	0.39409	0.49143	0.84116
Average daily gain regression using averaged start and end body weight and all													

body weight records within interval, kg/d													
Overall	.	1.2912	1.2631	1.1159	1.107	0.05572	0	2	.	0.03836	0.00684	0.86514	0.30602
Day 1--42	.	1.5959	1.8683	1.4987	1.6899	0.1068	72.8	74.9	.	0.10116	0.85508	0.70557	0.01465
Day 42-77	.	1.0461	0.7816	0.8421	0.6676	0.1129	79.1	81.2	.	0.12862	0.03775	0.69177	0.2724
Day 77-106	.	1.1384	1.1864	1.0956	0.9683	0.09858	63.9	65.9	.	0.4465	0.17816	0.37794	0.8171
Overall	Initial BW	1.2899	1.267	1.1111	1.1092	0.05559	10.9	12.9	0.2204	0.0342	0.00676	0.85021	0.25459
Day 1--42	Initial BW	1.5956	1.8692	1.4975	1.6905	0.108	83.9	85.9	0.8772	0.10528	0.85702	0.70978	0.01541
Day 42-77	Initial BW	1.0436	0.7892	0.8325	0.672	0.1127	88.7	90.7	0.2298	0.14048	0.03763	0.6775	0.32531
Day 77-106	Initial BW	1.1347	1.1983	1.0806	0.9753	0.09544	70.4	72.4	0.0288	0.40707	0.1673	0.37896	0.65216
Overall	Average BW	1.2801	1.2558	1.119	1.1223	0.04948	-1.7	0.3	0.0002	0.03878	0.00799	0.78078	0.25755
Day 1--42	Average BW	1.5949	1.8646	1.4969	1.6964	0.1035	79.6	81.6	0.0353	0.08685	0.89173	0.73591	0.01182
Day 42-77	Average BW	1.0303	0.7738	0.8488	0.6843	0.1097	85.9	87.9	0.0343	0.15941	0.05539	0.67589	0.24817
Day 77-106	Average BW	1.108	1.1672	1.1084	1.0052	0.0889	62.7	64.7	0.0003	0.63605	0.36282	0.36221	0.85297
Average daily gain regression using all individual body weight records within interval, kg/d													
Overall	.	1.2146	1.2018	1.0697	1.0536	0.05722	3	5	.	0.09719	0.01955	0.97699	0.36188
Day 1--42	.	1.3313	1.6621	1.3225	1.5274	0.1079	74	76.1	.	0.08571	0.60833	0.56238	0.01471
Day 42-77	.	1.0461	0.7816	0.8421	0.6676	0.1129	79.1	81.2	.	0.12862	0.03775	0.69177	0.2724
Day 77-106	.	1.1389	1.1944	1.105	0.971	0.09857	63.9	65.9	.	0.4327	0.18374	0.34047	0.82081
Overall	Initial BW	1.213	1.2069	1.0633	1.0566	0.05655	12.8	14.8	0.1116	0.08153	0.01842	0.99565	0.28387
Day 1--42	Initial BW	1.3299	1.6664	1.317	1.53	0.1086	84.6	86.6	0.4721	0.07855	0.60711	0.57131	0.0131
Day 42-77	Initial BW	1.0436	0.7892	0.8325	0.672	0.1127	88.7	90.7	0.2298	0.14048	0.03763	0.6775	0.32531
Day 77-106	Initial BW	1.1353	1.2058	1.0906	0.9776	0.09578	70.8	72.8	0.0363	0.39823	0.17418	0.34121	0.66302
Overall	Average BW	1.2033	1.1942	1.0729	1.0693	0.05078	1.2	3.2	0.0002	0.10993	0.02533	0.95676	0.31404
Day 1--42	Average BW	1.3303	1.6585	1.3207	1.5338	0.1049	81.1	83.1	0.0419	0.07243	0.56354	0.58543	0.01209
Day 42-77	Average BW	1.0303	0.7738	0.8488	0.6843	0.1097	85.9	87.9	0.0343	0.15941	0.05539	0.67589	0.24817
Day 77-106	Average BW	1.1091	1.1756	1.1176	1.0071	0.08938	63.2	65.3	0.0005	0.60962	0.36918	0.32366	0.85674
Gain:feed based, kg/kg													
Overall	.	0.09828	0.09794	0.09714	0.09961	0.004528	-281.1	-279.1	.	0.98447	0.87554	0.75835	0.85495
Day 1--42	.	0.1334	0.1479	0.1259	0.1521	0.009715	-195.8	-193.8	.	0.18756	0.42041	0.53879	0.05233
Day 42-77	.	0.08966	0.06448	0.07856	0.06647	0.01005	-192	-190	.	0.23874	0.20749	0.50707	0.14392
Day 77-106	.	0.1038	0.101	0.1096	0.1004	0.01004	-191.9	-189.9	.	0.91327	0.96978	0.753	0.5187
Gain:feed using averaged day 0 and day 1 and averaged day 105 and day 106 total gain, kg/kg													
Overall	.	0.1106	0.1064	0.1057	0.1096	0.004084	-292.7	-290.6	.	0.799	0.8391	0.3302	0.9566
Day 1--42	.	0.1334	0.1479	0.1259	0.1521	0.009715	-195.8	-193.8	.	0.1876	0.4204	0.5388	0.0523
Day 42-77	.	0.08966	0.06448	0.07856	0.06647	0.01005	-192	-190	.	0.2387	0.2075	0.5071	0.1439
Day 77-106	.	0.1038	0.101	0.1096	0.1004	0.01004	-191.9	-189.9	.	0.9133	0.9698	0.753	0.5187
Feed:gain based on total gain, kg/kg													
Overall	.	10.3263	10.5273	10.6527	10.4997	0.5064	239.1	241.1	.	0.97403	0.76944	0.72132	0.92761
Feed:gain using averaged day 0 and													

day 1 and averaged day 105 and day 106 total gain, kg/kg														
Overall	.	9.1616	9.5505	9.685	9.402	0.3702	212.1	214.1	.	0.7773	0.6074	0.3681	0.9219

Appendix Table 2. Effects of GreenFeed model and covariate structure on methane responses in cashew nut shell extract-supplemented finishing heifers

			DynOmik, g/d							*P*-value				
Variable	LS Mean Model	Cov	0	2.5	5	7.5	SEM	AIC	BIC	Cov	Trt	Linear	Quadratic	Cubic
Methane emission, g/d														
Overall	Beck	.	193.87	183.66	179.67	180.18	9.2562	567.1	569.1	.	0.58942	0.24789	0.53098	0.96364
Day 1-42	Beck	.	192.64	197.81	188.96	169.87	12.8528	555.7	557.6	.	0.4175	0.1695	0.31789	0.94256
Day 42-77	Beck	.	200.13	187.63	184.06	183.11	10.5469	549.2	551.2	.	0.52921	0.21228	0.55239	0.88441
Day 77-106	Beck	.	183.14	168.82	162.45	175.07	9.9161	573.6	575.6	.	0.3782	0.45728	0.14066	0.78246
Overall	Beck	Initial BW	193.34	184.46	179.01	181.96	8.9756	564.6	566.6	0.029	0.6078	0.29386	0.47446	0.89133
Day 1-42	Beck	Initial BW	192.74	197.57	191.7	173.62	12.3951	552	553.9	0.0205	0.51577	0.24092	0.32423	0.97578
Day 42-77	Beck	Initial BW	199.25	188.13	183.14	184.45	10.3452	548.1	550.1	0.0724	0.5636	0.24983	0.51388	0.9966
Day 77-106	Beck	Initial BW	182.52	169.96	160.98	177.19	9.7083	571.8	573.8	0.0476	0.31773	0.53291	0.10728	0.58297
Overall	Beck	Average BW	192.54	182.77	180.54	182.61	8.8941	563.7	565.7	0.0145	0.70059	0.39354	0.46928	0.92788
Day 1-42	Beck	Average BW	193.07	195.67	191.82	173.97	12.5819	553.2	555.1	0.0388	0.58326	0.26348	0.38486	0.88232
Day 42-77	Beck	Average BW	198.12	186.9	184.62	184.77	10.1147	546.2	548.1	0.0187	0.65177	0.3152	0.541	0.87476
Day 77-106	Beck	Average BW	181.12	167.93	162.84	178.01	9.6909	571.7	573.7	0.0331	0.39742	0.72086	0.10996	0.75378
Overall	Day-hour	.	187.24	179.77	174.97	172.12	9.3191	569.4	571.4	.	0.61351	0.20302	0.79064	0.98532
Day 1-42	Day-hour	.	192.5	197.01	186.74	165.3	12.7537	556.2	558.2	.	0.28935	0.10299	0.28548	0.94517
Day 42-77	Day-hour	.	190.28	184.76	179.54	173.73	10.7745	553.8	555.7	.	0.67697	0.22497	0.98864	0.98422
Day 77-106	Day-hour	.	176.18	162.55	160.02	166.65	9.9392	574	576	.	0.56451	0.45045	0.26865	0.96143
Overall	Day-hour	Initial BW	186.61	180.65	174.38	174.45	8.9588	565.8	567.8	0.0153	0.66481	0.25766	0.71641	0.85748
Day 1-42	Day-hour	Initial BW	192.57	196.75	189.65	169.2	12.2564	552.2	554.1	0.0166	0.37379	0.15183	0.28752	0.96715
Day 42-77	Day-hour	Initial BW	189.17	185.16	178.63	175.51	10.5315	552.1	554	0.0541	0.74385	0.28182	0.96377	0.89326
Day 77-106	Day-hour	Initial BW	175.53	163.74	158.56	168.86	9.7061	571.9	573.9	0.0401	0.53272	0.53007	0.21533	0.82217
Overall	Day-hour	Average BW	185.77	178.75	176.15	175.33	8.8254	564.2	566.2	0.0053	0.78274	0.36332	0.70399	0.94188
Day 1-42	Day-hour	Average BW	192.92	194.76	189.78	169.59	12.4489	553.4	555.4	0.032	0.43995	0.1704	0.34778	0.8685
Day 42-77	Day-hour	Average BW	187.9	183.84	180.4	176.11	10.1954	549.1	551	0.008	0.83788	0.36543	0.99044	0.97195
Day 77-106	Day-hour	Average BW	173.98	161.57	160.54	169.96	9.6234	570.9	573	0.018	0.61448	0.74409	0.21456	0.98026
Overall	Full	.	187.42	178.54	176.54	173.3	9.2397	567.6	569.6	.	0.67234	0.25664	0.7434	0.83104
Day 1-42	Full	.	193.37	197.63	188.14	166.72	12.7119	553.8	555.8	.	0.30453	0.10696	0.28391	0.97211
Day 42-77	Full	.	190.1	182.97	181.14	174.83	10.7253	551.9	553.9	.	0.74546	0.28817	0.96736	0.82767
Day 77-106	Full	.	176.19	161.96	159.78	166.35	9.9285	573.8	575.8	.	0.5435	0.44173	0.25641	0.93526
Overall	Full	Initial BW	186.91	179.41	175.83	175.31	8.8841	564.2	566.2	0.0168	0.71807	0.30587	0.67194	0.9814
Day 1-42	Full	Initial BW	193.42	197.37	190.57	170.17	12.302	550.6	552.5	0.0258	0.38449	0.15216	0.29033	0.95401
Day 42-77	Full	Initial BW	189.18	183.47	180.2	176.41	10.4579	550.1	552.1	0.0491	0.80567	0.34092	0.92142	0.94626
Day 77-106	Full	Initial BW	175.52	163.16	158.23	168.58	9.6795	571.5	573.5	0.0363	0.51036	0.51962	0.20215	0.84224
Overall	Full	Average BW	186.02	177.57	177.59	176.12	8.7514	562.6	564.6	0.0059	0.8028	0.42306	0.66696	0.78139
Day 1-42	Full	Average BW	193.76	195.61	190.75	170.51	12.4654	551.7	553.6	0.0451	0.44089	0.1681	0.34279	0.86358
Day 42-77	Full	Average BW	187.95	182.16	182.04	176.86	10.16	547.5	549.4	0.0089	0.87061	0.43304	0.97417	0.79984
Day 77-106	Full	Average BW	173.95	160.96	160.29	169.72	9.5877	570.5	572.5	0.0153	0.5912	0.73815	0.20172	0.9545
CO_2 emission, g/d														
Overall	Beck	.	11,196	11,147	10,802	10,917	311.31	961.6	963.6	.	0.72136	0.36757	0.77737	0.55423
Day 1-42	Beck	.	10,179	10,530	10,056	9,924	349.33	894.6	896.6	.	0.59426	0.41743	0.46789	0.4207
Day 42-77	Beck	.	11,680	11,737	11,361	11,417	359.75	925.6	927.5	.	0.81714	0.43997	0.99871	0.5716
Day 77-106	Beck	.	11,239	11,059	10,754	10,948	308.46	957.6	959.6	.	0.63286	0.35708	0.50445	0.61398
Overall	Beck	Initial BW	11,155	11,213	10,748	11,070	229.46	921.9	923.9	<.0001	0.39185	0.45563	0.53492	0.16658

Day 1-42	Beck	Initial BW	10,195	10,513	10,182	10,099	285.12	867.8	869.7	<.0001	0.69874	0.61808	0.45787	0.44551
Day 42-77	Beck	Initial BW	11,593	11,775	11,256	11,570	262.27	886.4	888.3	<.0001	0.50978	0.59196	0.78938	0.17247
Day 77-106	Beck	Initial BW	11,196	11,132	10,650	11,086	247.23	927	929	<.0001	0.2819	0.42601	0.26532	0.18047
Overall	Beck	Average BW	11,090	11,075	10,872	11,132	193.77	903.3	905.4	<.0001	0.73028	0.92586	0.44357	0.41219
Day 1-42	Beck	Average BW	10,218	10,402	10,207	10,147	281.7	866.3	868.2	<.0001	0.91215	0.73888	0.64625	0.65713
Day 42-77	Beck	Average BW	11,506	11,671	11,409	11,593	208.87	863.1	865	<.0001	0.80312	0.9981	0.96066	0.32541
Day 77-106	Beck	Average BW	11,077	10,977	10,787	11,169	211.19	909.8	911.8	<.0001	0.542	0.9219	0.20806	0.42934
Overall	Day-hour	.	11,115	11,115	10,774	10,845	311.05	962.2	964.3	.	0.75878	0.38075	0.9034	0.56008
Day 1-42	Day-hour	.	10,157	10,529	10,038	9,872	347.95	894.2	896.1	.	0.53619	0.37657	0.41784	0.41092
Day 42-77	Day-hour	.	11,603	11,669	11,322	11,353	362.99	926.1	928.1	.	0.85025	0.47265	0.9606	0.60437
Day 77-106	Day-hour	.	11,151	11,000	10,733	10,839	304.65	957.1	959.1	.	0.70543	0.34229	0.64502	0.69145
Overall	Day-hour	Initial BW	11,070	11,177	10,728	11,009	225.88	920.8	922.8	<.0001	0.46163	0.50703	0.67972	0.17187
Day 1-42	Day-hour	Initial BW	10,173	10,511	10,165	10,049	281.21	866.4	868.3	<.0001	0.62819	0.55774	0.39433	0.43092
Day 42-77	Day-hour	Initial BW	11,518	11,713	11,232	11,515	264.78	886.9	888.8	<.0001	0.58636	0.66034	0.85886	0.19965
Day 77-106	Day-hour	Initial BW	11,099	11,082	10,625	10,986	241.87	925.5	927.5	<.0001	0.37494	0.42624	0.39286	0.20405
Overall	Day-hour	Average BW	11,008	11,038	10,861	11,074	188.75	901.1	903.1	<.0001	0.83389	0.98025	0.60201	0.44325
Day 1-42	Day-hour	Average BW	10,196	10,399	10,190	10,097	277.59	864.8	866.7	<.0001	0.86961	0.67601	0.57353	0.64523
Day 42-77	Day-hour	Average BW	11,432	11,605	11,393	11,543	210.94	863.6	865.6	<.0001	0.8625	0.89279	0.95528	0.3997
Day 77-106	Day-hour	Average BW	10,986	10,923	10,763	11,074	206.52	908.1	910.1	<.0001	0.70066	0.90442	0.32021	0.49295
Overall	Full	.	11,105	11,106	10,783	10,857	309.14	961.5	963.5	.	0.78983	0.41273	0.89919	0.57582
Day 1-42	Full	.	10,157	10,529	10,038	9,872	347.94	894.2	896.1	.	0.53612	0.37657	0.41783	0.41082
Day 42-77	Full	.	11,580	11,639	11,310	11,382	359.41	925.1	927.1	.	0.8828	0.54085	0.98536	0.60481
Day 77-106	Full	.	11,162	10,994	10,710	10,832	305.47	957.1	959.1	.	0.66062	0.31602	0.60484	0.67456
Overall	Full	Initial BW	11,068	11,169	10,730	11,014	225.02	920.4	922.4	<.0001	0.4789	0.52431	0.66319	0.18065
Day 1-42	Full	Initial BW	10,173	10,511	10,165	10,049	281.21	866.4	868.3	<.0001	0.62809	0.55774	0.39432	0.43079
Day 42-77	Full	Initial BW	11,514	11,690	11,221	11,533	261.7	885.8	887.8	<.0001	0.58763	0.70802	0.78214	0.2013
Day 77-106	Full	Initial BW	11,117	11,071	10,607	10,979	242	925.2	927.2	<.0001	0.33346	0.38073	0.34469	0.20581
Overall	Full	Average BW	11,005	11,033	10,862	11,077	188.2	900.8	902.8	<.0001	0.83636	0.95545	0.59161	0.45345
Day 1-42	Full	Average BW	10,196	10,399	10,190	10,097	277.58	864.8	866.7	<.0001	0.86955	0.676	0.57351	0.64507
Day 42-77	Full	Average BW	11,424	11,587	11,385	11,559	208.73	862.7	864.6	<.0001	0.85517	0.81774	0.97716	0.40095
Day 77-106	Full	Average BW	10,998	10,915	10,763	11,070	205.64	907.3	909.3	<.0001	0.69415	0.94187	0.29963	0.52303
Methane yield, g/kg DMI														
Overall	Beck	.	16.3581	14.5865	16.4869	16.9713	0.8101	294.2	296.3	.	0.13678	0.27293	0.13507	0.12596
Day 1-42	Beck	.	16.3594	15.6224	16.5619	15.744	1.0354	298.8	300.7	.	0.87345	0.83971	0.96686	0.41711
Day 42-77	Beck	.	16.468	14.4254	16.5427	17.1702	0.9185	290.5	292.5	.	0.15318	0.26742	0.11827	0.13804
Day 77-106	Beck	.	16.0114	14.0528	16.525	17.496	1.0844	325.7	327.7	.	0.11327	0.12637	0.14293	0.17847
Overall	Beck	Initial BW	16.3479	14.6021	16.4741	17.0061	0.8189	301.3	303.3	0.6345	0.14247	0.26402	0.13434	0.13982
Day 1-42	Beck	Initial BW	16.3634	15.6133	16.6676	15.8885	1.0417	304.4	306.3	0.2777	0.8597	0.93441	0.98808	0.38976
Day 42-77	Beck	Initial BW	16.4539	14.4334	16.528	17.1916	0.9287	297.4	299.4	0.7451	0.16008	0.26331	0.11967	0.15013
Day 77-106	Beck	Initial BW	16.0044	14.0658	16.5083	17.5201	1.1001	332.3	334.3	0.8396	0.11885	0.12718	0.14417	0.19505
Overall	Beck	Average BW	16.3557	14.5848	16.4885	16.9758	0.8222	301.8	303.8	0.9601	0.14383	0.27887	0.13842	0.12926
Day 1-42	Beck	Average BW	16.3703	15.5688	16.6337	15.8469	1.054	305.2	307.2	0.5273	0.85491	0.91169	0.99404	0.38535

Day 42-77	Beck	Average BW	16.4576	14.4216	16.5456	17.1788	0.9293	297.9	299.8	0.8914	0.15854	0.26835	0.12189	0.1417
Day 77-106	Beck	Average BW	16.0811	14.0838	16.5115	17.3943	1.1004	332.4	334.4	0.5071	0.13894	0.16853	0.15204	0.17799
Overall	Day-hour	.	15.8154	14.2629	16.0187	16.2079	0.8035	294.9	297	.	0.254	0.38612	0.24726	0.1456
Day 1-42	Day-hour	.	16.3525	15.5592	16.3635	15.3149	1.0332	299.9	301.8	.	0.82388	0.60873	0.89618	0.41773
Day 42-77	Day-hour	.	15.6787	14.1641	16.1011	16.2886	0.9052	291.2	293.2	.	0.31937	0.32012	0.31676	0.17446
Day 77-106	Day-hour	.	15.4111	13.5453	16.2639	16.644	1.076	325	327	.	0.1332	0.15334	0.25722	0.11641
Overall	Day-hour	Initial BW	15.7964	14.2892	16.0009	16.2788	0.8101	301.5	303.5	0.4056	0.25875	0.35381	0.23747	0.16705
Day 1-42	Day-hour	Initial BW	16.3553	15.5489	16.4819	15.4735	1.0375	305.3	307.2	0.2387	0.82774	0.70462	0.91749	0.38616
Day 42-77	Day-hour	Initial BW	15.6479	14.1752	16.0758	16.3379	0.9138	297.8	299.8	0.5317	0.32458	0.29945	0.31071	0.19434
Day 77-106	Day-hour	Initial BW	15.3996	13.5664	16.238	16.6833	1.0911	331.5	333.5	0.7416	0.14104	0.15113	0.25491	0.13301
Overall	Day-hour	Average BW	15.7906	14.2456	16.0386	16.2623	0.8152	302.2	304.2	0.5972	0.24355	0.35225	0.24347	0.14568
Day 1-42	Day-hour	Average BW	16.3643	15.4961	16.449	15.4353	1.0508	306.2	308.1	0.4665	0.8175	0.68851	0.94121	0.379
Day 42-77	Day-hour	Average BW	15.6289	14.1448	16.1192	16.3385	0.9135	298.2	300.1	0.5208	0.30573	0.28644	0.31915	0.17588
Day 77-106	Day-hour	Average BW	15.4488	13.5622	16.255	16.5873	1.0953	331.9	333.9	0.7147	0.15331	0.18462	0.26703	0.11844
Overall	Full	.	15.8134	14.1808	16.1898	16.3054	0.7936	292.7	294.7	.	0.16651	0.29897	0.24002	0.09499
Day 1-42	Full	.	16.433	15.6357	16.4736	15.4452	1.0395	298.4	300.4	.	0.82708	0.63548	0.90558	0.40946
Day 42-77	Full	.	15.6442	14.0622	16.2859	16.3397	0.9024	289.6	291.5	.	0.2291	0.2537	0.33343	0.11791
Day 77-106	Full	.	15.4134	13.4967	16.2289	16.6203	1.0703	324.3	326.3	.	0.12746	0.15547	0.2427	0.11211
Overall	Full	Initial BW	15.7992	14.2052	16.1697	16.362	0.7999	299.3	301.4	0.445	0.17299	0.27938	0.23212	0.11002
Day 1-42	Full	Initial BW	16.4349	15.6263	16.5615	15.5699	1.0478	304.3	306.2	0.3342	0.83131	0.71283	0.92523	0.38808
Day 42-77	Full	Initial BW	15.6183	14.0764	16.2592	16.3844	0.9098	296.2	298.1	0.5149	0.23647	0.2393	0.32725	0.13329
Day 77-106	Full	Initial BW	15.4005	13.5201	16.1985	16.6639	1.0849	330.8	332.8	0.7096	0.13533	0.15236	0.23947	0.12971
Overall	Full	Average BW	15.7926	14.1664	16.2054	16.3474	0.8043	300	302	0.6443	0.16209	0.2781	0.2383	0.09584
Day 1-42	Full	Average BW	16.4415	15.5913	16.5309	15.5286	1.0585	305	307	0.5966	0.82358	0.69294	0.9384	0.3854
Day 42-77	Full	Average BW	15.602	14.0462	16.3037	16.3796	0.9104	296.6	298.5	0.5533	0.22095	0.23098	0.33764	0.11907
Day 77-106	Full	Average BW	15.4443	13.5105	16.2218	16.5738	1.0899	331.3	333.3	0.7627	0.14499	0.18321	0.25149	0.11436

Methane intensity, g/kg calculated ADG														
Overall	Beck	.	167.02	153.64	174.29	167.82	11.3916	580.4	582.4	.	0.56652	0.63023	0.74588	0.19961
Day 1-42	Beck	.	128.34	125.01	142.62	117.2	12.108	506.8	508.7	.	0.50322	0.76829	0.34853	0.21519
Day 42-77	Beck	.	369.55	335.56	229.39	102.13	170.69	813	815	.	0.64901	0.20761	0.7697	0.94253
Day 77-106	Beck	.	192.84	276.32	189.1	328.13	79.5177	760	762	.	0.47285	0.32729	0.69937	0.21678
Overall	Beck	Initial BW	167.18	153.39	174.53	167.26	11.5111	582.1	584.1	0.5901	0.55725	0.65788	0.76089	0.18883
Day 1-42	Beck	Initial BW	128.4	124.79	143.34	117.65	12.2759	508.4	510.2	0.7045	0.49696	0.80121	0.35295	0.20611
Day 42-77	Beck	Initial BW	368.61	335.77	228.63	103.27	172.63	809.6	811.5	0.9049	0.66126	0.21557	0.7737	0.93768
Day 77-106	Beck	Initial BW	192.92	269.1	196.6	323.58	80.0232	757.3	759.3	0.4381	0.55083	0.32788	0.72513	0.28865
Overall	Beck	Average BW	168.26	154.42	174.16	165.07	11.122	578.3	580.3	0.0387	0.57701	0.8277	0.81828	0.1775
Day 1-42	Beck	Average BW	128.23	125.43	141.97	116.55	12.3476	508.6	510.4	0.7159	0.52177	0.7351	0.34268	0.24389
Day 42-77	Beck	Average BW	375.81	338.06	227.14	97.9133	172.45	809.8	811.7	0.6933	0.63296	0.19764	0.77586	0.93884
Day 77-106	Beck	Average BW	202.3	275.12	193.1	312.07	78.0322	754.8	756.7	0.0606	0.59342	0.43831	0.74242	0.25713
Overall	Day-hour	.	161.53	150.58	169.07	160.22	10.7183	575.3	577.3	.	0.63772	0.74688	0.91732	0.21306
Day 1-42	Day-hour	.	127.85	124.33	141.5	114.44	12.303	509.6	511.4	.	0.47741	0.67514	0.32932	0.21923
Day 42-77	Day-hour	.	338.97	335.1	225.26	109.03	155.46	790.8	792.8	.	0.66888	0.23052	0.70826	0.88352
Day 77-106	Day-hour	.	185.89	264.61	186.77	306.87	74.4312	753.1	755.1	.	0.51887	0.34955	0.75935	0.24099
Overall	Day-hour	Initial BW	161.62	150.46	169.17	159.9	10.8686	577.2	579.2	0.7771	0.63595	0.76657	0.92623	0.21017
Day 1-42	Day-hour	Initial BW	127.92	124.08	142.35	114.96	12.4703	511.1	512.9	0.6696	0.47088	0.71189	0.33346	0.20755
Day 42-77	Day-hour	Initial BW	338.37	335.13	221.47	109.87	155.84	801.5	803.4	0.939	0.66981	0.23067	0.71375	0.86487
Day 77-106	Day-hour	Initial BW	186	257.97	193.57	302.57	74.9368	750.6	752.6	0.4484	0.59583	0.35114	0.78498	0.31579
Overall	Day-hour	Average BW	162.46	151.19	168.84	157.75	10.621	574.6	576.6	0.0872	0.6379	0.93745	0.99293	0.19819
Day 1-42	Day-hour	Average BW	127.76	124.67	140.98	113.92	12.5587	511.4	513.2	0.7786	0.49175	0.653	0.32665	0.24431
Day 42-77	Day-hour	Average BW	344.7	337.25	224.93	103.56	157.34	787.7	789.6	0.6845	0.65132	0.21833	0.70679	0.88886
Day 77-106	Day-hour	Average BW	194.39	263.49	190.26	291.55	73.1682	748.2	750.2	0.0657	0.64079	0.46606	0.8074	0.28409
Overall	Full	.	161.76	149.76	171.61	161.37	10.7386	574.6	576.6	.	0.50549	0.64822	0.93067	0.14897
Day 1-42	Full	.	128.48	125.56	142.62	115.38	12.3656	508.2	510.1	.	0.47261	0.68422	0.3117	0.22242
Day 42-77	Full	.	360.85	329.12	227.08	96.8275	162.87	809.2	811.1	.	0.63113	0.19817	0.74955	0.9514
Day 77-106	Full	.	186.29	267.53	185.27	308.24	74.798	753.6	755.6	.	0.50473	0.3547	0.75889	0.22645
Overall	Full	Initial BW	161.84	149.61	171.75	161.03	10.8725	576.5	578.5	0.7378	0.503	0.66705	0.94072	0.14611
Day 1-42	Full	Initial BW	128.52	125.41	143.1	115.67	12.5431	509.9	511.7	0.8001	0.4741	0.70698	0.3167	0.21902
Day 42-77	Full	Initial BW	359.84	329.29	226.36	98.2645	164.74	805.8	807.7	0.8835	0.645	0.20666	0.75436	0.94608
Day 77-106	Full	Initial BW	186.4	261.01	192.18	304.01	75.3155	751.1	753	0.455	0.5826	0.35605	0.78539	0.298
Overall	Full	Average BW	162.7	150.37	171.42	159.04	10.5955	573.7	575.7	0.0735	0.50931	0.82243	0.99834	0.13592
Day 1-42	Full	Average BW	128.34	126.08	141.82	114.6	12.5911	509.9	511.8	0.6548	0.48805	0.64688	0.30422	0.25557
Day 42-77	Full	Average BW	366.15	331.32	224.36	92.7223	164.63	806	807.9	0.7126	0.61714	0.18971	0.75585	0.94571
Day 77-106	Full	Average BW	194.69	266.37	188.8	292.94	73.5715	748.7	750.6	0.068	0.6244	0.47096	0.8072	0.2674
Methane intensity, g/kg calculated ADG														
	Beck	.	149.29	139.46	161.2	151.18	9.936	575	577	.	0.40349	0.51088	0.99184	0.12067
Day 1-42 (average d 0/1)	Beck	.	110.13	113.14	116.1	104.85	10.787	495.9	497.8	.	0.89305	0.78742	0.49578	0.75636
Day 42-77	Beck	.	369.55	335.56	229.39	102.13	170.69	813	815	.	0.64901	0.20761	0.7697	0.94253
Day 77-106 (average d 105/106)	Beck	.	159.01	155.23	162.87	181.91	26.3534	642.9	644.9	.	0.8828	0.47792	0.63223	0.99997
	Beck	Initial BW	149.25	139.53	161.14	151.34	10.063	577.2	579.2	0.865	0.41711	0.50839	0.99601	0.1286
Day 1-42 (average d 0/1)	Beck	Initial BW	110.27	112.64	117.79	105.89	10.835	496.9	498.8	0.3189	0.88493	0.86788	0.4956	0.66632
Day 42-77	Beck	Initial BW	368.61	335.77	228.63	103.27	172.63	809.6	811.5	0.9049	0.66126	0.21557	0.7737	0.93768
Day 77-106 (average d 105/106)	Beck	Initial BW	159.04	153.11	165.07	180.58	26.5538	642.6	644.5	0.4913	0.8829	0.47871	0.65506	0.89455

	Beck	Average BW	150.19	140.07	160.61	149.54	9.8758	575.2	577.2	0.1305	0.44723	0.65451	0.95844	0.12249
Day 1-42 (average d 0/1)	Beck	Average BW	110.15	113.07	116.21	104.96	11.0159	498.1	499.9	0.943	0.89761	0.799	0.50399	0.75357
Day 42-77	Beck	Average BW	375.81	338.06	227.14	97.9133	172.45	809.8	811.7	0.6933	0.63296	0.19764	0.77586	0.93884
Day 77-106 (average d 105/106)	Beck	Average BW	162.06	154.85	164.16	176.74	25.9109	640.1	642.1	0.0684	0.93818	0.61401	0.67127	0.89829
	Day-hour	.	144.47	136.7	156.49	144.27	9.3892	570.3	572.3	.	0.44279	0.62669	0.79889	0.12839
Day 1-42 (average d 0/1)	Day-hour	.	109.55	112.44	115.1	102.08	10.7518	496.9	498.7	.	0.83954	0.68069	0.44969	0.73593
Day 42-77	Day-hour	.	338.97	335.1	221.84	109.03	153.94	804.8	806.7	.	0.65782	0.22241	0.70948	0.86652
Day 77-106 (average d 105/106)	Day-hour	.	153.32	149.21	161.03	171.67	25.1803	638.3	640.2	.	0.91476	0.51579	0.74699	0.8664
	Day-hour	Initial BW	144.35	136.87	156.38	144.72	9.5085	572.4	574.4	0.653	0.4638	0.60512	0.81243	0.14159
Day 1-42 (average d 0/1)	Day-hour	Initial BW	109.7	111.93	116.85	103.15	10.7985	497.9	499.7	0.3132	0.83662	0.76018	0.44912	0.6448
Day 42-77	Day-hour	Initial BW	338.37	335.13	221.47	109.87	155.84	801.5	803.4	0.939	0.66981	0.23067	0.71375	0.86487
Day 77-106 (average d 105/106)	Day-hour	Initial BW	153.35	147.29	163	170.42	25.3893	638	640	0.5167	0.90515	0.5177	0.76937	0.77288
	Day-hour	Average BW	145.09	137.14	155.99	142.91	9.4367	571.6	573.6	0.2549	0.4751	0.75685	0.76874	0.13267
Day 1-42 (average d 0/1)	Day-hour	Average BW	109.58	112.32	115.28	102.25	10.9834	499	500.9	0.9124	0.84773	0.69791	0.45941	0.72936
Day 42-77	Day-hour	Average BW	344.89	337.57	219.25	104.13	155.69	801.7	803.6	0.6895	0.63969	0.21017	0.7147	0.86247
Day 77-106 (average d 105/106)	Day-hour	Average BW	156.01	148.86	162.13	166.82	24.8576	635.9	637.9	0.0857	0.95183	0.65274	0.79194	0.77164
	Full	.	144.51	135.86	158.11	145.33	9.3514	568.9	571	.	0.33586	0.53067	0.81259	0.09158
Day 1-42 (average d 0/1)	Full	.	110.06	113.22	116.13	102.79	10.7227	494.8	496.7	.	0.82833	0.68992	0.42728	0.72408
Day 42-77	Full	.	360.85	329.12	227.08	96.8275	162.87	809.2	811.1	.	0.63113	0.19817	0.74955	0.9514
Day 77-106 (average d 105/106)	Full	.	153.65	149.9	159.96	171.98	25.1659	638.1	640.1	.	0.92068	0.52711	0.73025	0.90746
	Full	Initial BW	144.42	136.01	157.99	145.67	9.4626	571.1	573.1	0.6929	0.35478	0.51795	0.82434	0.10142
Day 1-42 (average d 0/1)	Full	Initial BW	110.2	112.77	117.58	103.66	10.7926	496.1	497.9	0.3801	0.8259	0.75662	0.42874	0.64737
Day 42-77	Full	Initial BW	359.84	329.29	226.36	98.2645	164.74	805.8	807.7	0.8835	0.645	0.20666	0.75436	0.94608
Day 77-106 (average d 105/106)	Full	Initial BW	153.68	148.08	161.89	170.8	25.3826	637.9	639.9	0.5349	0.91467	0.52881	0.75275	0.81584
	Full	Average BW	145.14	136.3	157.63	144.05	9.3707	570.1	572.1	0.2284	0.36796	0.64871	0.78472	0.0944
Day 1-42 (average d 0/1)	Full	Average BW	110.06	113.23	116.12	102.77	10.9423	497	498.8	0.9907	0.83328	0.69448	0.4327	0.73072
Day 42-77	Full	Average BW	366.15	331.32	224.36	92.7223	164.63	806	807.9	0.7126	0.61714	0.18971	0.75585	0.94571
Day 77-106 (average d 105/106)	Full	Average BW	156.26	149.54	161.05	167.23	24.8747	635.9	637.9	0.0928	0.95807	0.66223	0.77434	0.81421
Methane intensity regressions, g/kg ADG														
	Beck	.	152.79	148.04	168.23	158.52	10.6614	582.9	584.9	.	0.48442	0.4042	0.80094	0.20863
Day 1-42 (average d 0/1)	Beck	.	110.58	109.72	116.55	106.32	9.7691	496.7	498.5	.	0.89303	0.89082	0.61747	0.54247
Day 42-77	Beck	.	922.66	400.07	238.44	732.32	610.99	961.6	963.5	.	0.80193	0.77458	0.37173	0.90666
Day 77-106 (average d 105/106)	Beck	.	166.39	148.22	159.17	189.24	22.162	624.6	626.5	.	0.57486	0.38004	0.23172	0.91064
	Beck	Initial BW	152.67	148.23	168.08	158.92	10.7829	584.8	586.8	0.673	0.49978	0.39337	0.81235	0.22637
Day 1-42 (average d 0/1)	Beck	Initial BW	110.8	109.44	117.48	107.25	9.8469	498.1	500	0.38	0.88168	0.95176	0.63745	0.49907
Day 42-77	Beck	Initial BW	916.63	404	228.74	744.34	617.77	955.5	957.5	0.7696	0.80272	0.78887	0.37085	0.88944
Day 77-106 (average d 105/106)	Beck	Initial BW	166.4	147.41	160.02	188.73	22.412	624.9	626.9	0.7539	0.58245	0.38361	0.24136	0.86543
	Beck	Average BW	153.58	148.57	167.71	157.08	10.6721	583.7	585.8	0.2185	0.54144	0.50974	0.77405	0.21412
Day 1-42 (average d 0/1)	Beck	Average BW	110.55	109.79	116.45	106.19	9.9819	499	500.9	0.9296	0.89659	0.884	0.61734	0.55642
Day 42-77	Beck	Average BW	937.71	405.5	234.54	720.57	617.84	955.9	957.8	0.7773	0.79919	0.75187	0.37521	0.90713

Day 77-106 (average d 105/106)	Beck	Average BW	168.39	147.97	160.01	185.85	22.0733	623.5	625.4	0.1583	0.62836	0.47501	0.24705	0.83261
	Day-hour	.	147.93	145.2	163.23	151.3	10.0445	577.8	579.8	.	0.52051	0.50538	0.62321	0.22465
Day 1-42 (average d 0/1)	Day-hour	.	109.96	109.05	115.39	103.49	9.6961	497.2	499.1	.	0.85042	0.76272	0.55864	0.53092
Day 42-77	Day-hour	.	829.54	401.99	230.05	658.69	549.46	952.9	954.8	.	0.83218	0.76897	0.41062	0.88125
Day 77-106 (average d 105/106)	Day-hour	.	160.37	142.69	157.34	178.47	20.9392	618.7	620.7	.	0.65445	0.42056	0.3093	0.75966
	Day-hour	Initial BW	147.73	145.48	163.04	152.04	10.1466	579.5	581.5	0.4905	0.53924	0.47434	0.64198	0.24992
Day 1-42 (average d 0/1)	Day-hour	Initial BW	110.19	108.77	116.34	104.44	9.7731	498.7	500.5	0.3745	0.84532	0.82398	0.57785	0.48685
Day 42-77	Day-hour	Initial BW	823.61	404.25	222.42	671.38	556.22	947	948.9	0.7798	0.83272	0.78648	0.4087	0.86634
Day 77-106 (average d 105/106)	Day-hour	Initial BW	160.38	142.07	157.98	178.07	21.1863	619.2	621.2	0.8015	0.65729	0.42459	0.31913	0.72958
	Day-hour	Average BW	148.44	145.56	162.82	150.18	10.1443	579.5	581.5	0.3808	0.56041	0.59964	0.60332	0.23187
Day 1-42 (average d 0/1)	Day-hour	Average BW	109.94	109.09	115.33	103.42	9.9119	499.6	501.4	0.9606	0.85411	0.7622	0.56139	0.54212
Day 42-77	Day-hour	Average BW	842.79	407.01	225.6	646.2	556.37	947.3	949.3	0.7892	0.82939	0.74531	0.41477	0.8814
Day 77-106 (average d 105/106)	Day-hour	Average BW	162.04	142.47	158.03	175.45	20.9363	618.1	620	0.2006	0.69784	0.51468	0.3296	0.69268
	Full	.	148	144.28	165.07	152.44	10.0663	577.2	579.2	.	0.40735	0.42206	0.63546	0.16663
Day 1-42 (average d 0/1)	Full	.	110.45	109.83	116.33	104.16	9.6827	495.2	497	.	0.83838	0.77152	0.53377	0.52161
Day 42-77	Full	.	911.45	394.73	235.9	704.71	582.82	957.6	959.5	.	0.79869	0.75189	0.37096	0.91212
Day 77-106 (average d 105/106)	Full	.	160.68	143.13	156.63	178.84	20.9647	618.8	620.7	.	0.65572	0.42831	0.29916	0.79253
	Full	Initial BW	147.85	144.54	164.85	153.05	10.1617	579	581	0.5186	0.42728	0.40162	0.65288	0.18676
Day 1-42 (average d 0/1)	Full	Initial BW	110.65	109.59	117.06	104.91	9.778	496.9	498.7	0.4556	0.83606	0.82034	0.55219	0.48798
Day 42-77	Full	Initial BW	906.08	398.27	226.65	717.8	589.39	951.6	953.5	0.7536	0.79916	0.76737	0.36913	0.89493
Day 77-106 (average d 105/106)	Full	Initial BW	160.69	142.6	157.19	178.49	21.2147	619.3	621.2	0.8274	0.6601	0.43231	0.30854	0.76598
	Full	Average BW	148.53	144.65	164.67	151.37	10.1411	578.8	580.8	0.3513	0.44745	0.50606	0.61679	0.17229
Day 1-42 (average d 0/1)	Full	Average BW	110.4	109.99	116.13	103.89	9.8828	497.6	499.4	0.8538	0.84138	0.75834	0.52972	0.5424
Day 42-77	Full	Average BW	924.35	399.56	230.82	693.16	589.64	952	953.9	0.7884	0.79611	0.7308	0.37455	0.91122
Day 77-106 (average d 105/106)	Full	Average BW	162.29	142.91	157.3	175.9	20.9845	618.2	620.2	0.2162	0.69971	0.52017	0.31896	0.72694
Methane intensity regressions, g/kg ADG														
Overall	Beck	.	161.13	156.42	174.42	167.02	11.1211	587.6	589.7	.	0.61441	0.44525	0.8955	0.28906
Day 1-42	Beck	.	130.72	113.27	149.85	120.11	11.3955	512.8	514.6	.	0.10007	0.92529	0.57944	0.01607
Day 42-77	Beck	.	922.66	400.07	238.44	732.32	610.99	961.6	963.5	.	0.80193	0.77458	0.37173	0.90666
Day 77-106	Beck	.	166.52	158.18	-1563.1	204.33	1005.39	1090.9	1092.9	.	0.43583	0.69911	0.33553	0.20279
Overall	Beck	Initial BW	161.17	156.36	174.47	166.89	11.2647	589.6	591.6	0.9012	0.61939	0.45512	0.89351	0.29039
Day 1-42	Beck	Initial BW	130.78	113.28	150.03	120.33	11.5839	514.7	516.5	0.8636	0.10469	0.91617	0.58643	0.01698
Day 42-77	Beck	Initial BW	916.63	404	228.74	744.34	617.77	955.5	957.5	0.7696	0.80272	0.78887	0.37085	0.88944
Day 77-106	Beck	Initial BW	94.6894	292.1	-1735.42	452.19	971.73	1078.5	1080.5	0.021	0.27554	0.81155	0.26277	0.10555
Overall	Beck	Average BW	162.15	157.11	173.76	165.15	11.0472	587.5	589.6	0.1252	0.68382	0.58134	0.86086	0.29506
Day 1-42	Beck	Average BW	130.53	113.75	149.24	119.22	11.6162	514.6	516.4	0.6134	0.11622	0.97586	0.55522	0.01995
Day 42-77	Beck	Average BW	937.71	405.5	234.54	720.57	617.84	955.9	957.8	0.7773	0.79919	0.75187	0.37521	0.90713

Day 77-106	Beck	Average BW	-82.3812	47.8773	-1514.82	567.57	961.4	1077.4	1079.4	0.0085	0.38723	0.92299	0.26471	0.16821
Overall	Day-hour	.	155.91	153.39	169.11	159.36	10.5025	582.8	584.8	.	0.66707	0.55487	0.71126	0.31561
Day 1-42	Day-hour	.	130.15	112.72	149.06	117.26	11.6979	516.6	518.4	.	0.10761	0.96451	0.53112	0.01831
Day 42-77	Day-hour	.	829.54	401.99	235.84	658.69	554.81	936.4	938.3	.	0.85034	0.7737	0.42528	0.89123
Day 77-106	Day-hour	.	160.47	152.13	-1480.81	193.28	936.13	1083	1085	.	0.42369	0.69227	0.32859	0.19696
Overall	Day-hour	Initial BW	155.86	153.45	169.07	159.51	10.6537	584.9	586.9	0.8867	0.67644	0.55206	0.71754	0.32696
Day 1-42	Day-hour	Initial BW	130.24	112.73	149.34	117.6	11.889	518.4	520.2	0.7975	0.11154	0.9804	0.53952	0.01908
Day 42-77	Day-hour	Initial BW	823.61	404.25	222.42	671.38	556.22	947	948.9	0.7798	0.83272	0.78648	0.4087	0.86634
Day 77-106	Day-hour	Initial BW	91.4172	278.81	-1636	428.67	904.04	1070.6	1072.6	0.0198	0.2668	0.80871	0.25754	0.10202
Overall	Day-hour	Average BW	156.62	153.89	168.54	157.79	10.5487	583.8	585.8	0.2422	0.71422	0.68279	0.68114	0.32447
Day 1-42	Day-hour	Average BW	129.99	113.12	148.55	116.54	11.9428	518.4	520.3	0.6969	0.12179	0.92628	0.51515	0.02222
Day 42-77	Day-hour	Average BW	842.27	406.23	236.83	644.85	562.22	930.8	932.8	0.7863	0.85046	0.75118	0.4331	0.89777
Day 77-106	Day-hour	Average BW	-70.5541	48.3952	-1426.37	541.15	894.22	1069.4	1071.5	0.0078	0.37651	0.92301	0.25747	0.1642
Overall	Full	.	156.2	152.46	171.31	160.76	10.5302	582.2	584.3	.	0.53931	0.46363	0.72888	0.23439
Day 1-42	Full	.	130.72	114.55	150.52	118.2	11.9327	516.5	518.3	.	0.11433	0.97599	0.48588	0.02097
Day 42-77	Full	.	911.45	394.73	235.9	704.71	582.82	957.6	959.5	.	0.79869	0.75189	0.37096	0.91212
Day 77-106	Full	.	160.77	152.19	-1469.75	193.34	930.38	1082.3	1084.3	.	0.42602	0.69255	0.32946	0.19845
Overall	Full	Initial BW	156.18	152.5	171.28	160.85	10.6699	584.3	586.3	0.9284	0.54964	0.46504	0.73362	0.24301
Day 1-42	Full	Initial BW	130.84	123.34	150.82	118.58	12.5315	531.2	533	0.7849	0.23159	0.86564	0.30044	0.06977
Day 42-77	Full	Initial BW	906.08	398.27	226.65	717.8	589.39	951.6	953.5	0.7536	0.79916	0.76737	0.36913	0.89493
Day 77-106	Full	Initial BW	92.0836	276.08	-1630.62	424.81	898.46	1069.9	1071.9	0.0199	0.26702	0.80649	0.25693	0.10255
Overall	Full	Average BW	156.93	152.97	170.76	159.28	10.5432	583.1	585.1	0.2145	0.5916	0.57783	0.70065	0.24085
Day 1-42	Full	Average BW	130.49	123.95	149.87	117.24	12.5652	531.1	533	0.604	0.2415	0.80173	0.27551	0.08152
Day 42-77	Full	Average BW	924.35	399.56	230.82	693.16	589.64	952	953.9	0.7884	0.79611	0.7308	0.37455	0.91122
Day 77-106	Full	Average BW	-67.0126	50.2877	-1417.81	536.69	889.12	1068.7	1070.7	0.0081	0.37821	0.92631	0.25845	0.16531
Methane energy loss, MJ/d														
Overall	Beck	.	10.7888	10.2207	9.9985	10.0268	0.5151	243.5	245.6	.	0.58942	0.24789	0.53098	0.96364
Day 1-42	Beck	.	10.7205	11.0079	10.5155	9.4534	0.7153	261	263	.	0.4175	0.1695	0.31789	0.94256
Day 42-77	Beck	.	11.1372	10.4418	10.2429	10.1901	0.5869	243	245	.	0.52921	0.21228	0.55239	0.88441
Day 77-106	Beck	.	10.1915	9.3946	9.0402	9.7429	0.5518	250.1	252.1	.	0.3782	0.45728	0.14066	0.78246
Overall	Beck	Initial BW	10.7596	10.2655	9.962	10.1263	0.4995	246.9	248.9	0.029	0.6078	0.29386	0.47446	0.89133
Day 1-42	Beck	Initial BW	10.7262	10.9947	10.6682	9.662	0.6898	263.1	265	0.0205	0.51577	0.24092	0.32423	0.97578
Day 42-77	Beck	Initial BW	11.088	10.4696	10.1917	10.2646	0.5757	247.7	249.7	0.0724	0.5636	0.24983	0.51388	0.9966
Day 77-106	Beck	Initial BW	10.1574	9.4581	8.9585	9.8604	0.5403	254	256.1	0.0476	0.31773	0.53291	0.10728	0.58297

Overall	Beck	Average BW	10.7147	10.1709	10.047	10.1621	0.495	245.9	248	0.0145	0.70059	0.39354	0.46928	0.92788
Day 1-42	Beck	Average BW	10.7445	10.8892	10.6747	9.6814	0.7002	264.3	266.3	0.0388	0.58326	0.26348	0.38486	0.88232
Day 42-77	Beck	Average BW	11.0252	10.4008	10.2744	10.2826	0.5629	245.7	247.7	0.0187	0.65177	0.3152	0.541	0.87476
Day 77-106	Beck	Average BW	10.0796	9.345	9.0619	9.9062	0.5393	253.9	255.9	0.0331	0.39742	0.72086	0.10996	0.75378
Overall	Day-hour	.	10.4198	10.0045	9.7371	9.5783	0.5186	245.9	247.9	.	0.61351	0.20302	0.79064	0.98532
Day 1-42	Day-hour	.	10.7125	10.9634	10.3921	9.1991	0.7097	261.6	263.5	.	0.28935	0.10299	0.28548	0.94517
Day 42-77	Day-hour	.	10.5889	10.2817	9.9914	9.6682	0.5996	247.6	249.5	.	0.67697	0.22497	0.98864	0.98422
Day 77-106	Day-hour	.	9.8044	9.046	8.9054	9.2739	0.5531	250.4	252.4	.	0.56451	0.45045	0.26865	0.96143
Overall	Day-hour	Initial BW	10.3849	10.053	9.7045	9.7084	0.4986	248.1	250.1	0.0153	0.66481	0.25766	0.71641	0.85748
Day 1-42	Day-hour	Initial BW	10.7164	10.9492	10.5539	9.4158	0.6821	263.3	265.2	0.0166	0.37379	0.15183	0.28752	0.96715
Day 42-77	Day-hour	Initial BW	10.5271	10.3039	9.9408	9.7672	0.5861	251.7	253.6	0.0541	0.74385	0.28182	0.96377	0.89326
Day 77-106	Day-hour	Initial BW	9.7682	9.1123	8.8241	9.3971	0.5401	254.1	256.1	0.0401	0.53272	0.53007	0.21533	0.82217
Overall	Day-hour	Average BW	10.3384	9.9476	9.8028	9.7572	0.4911	246.4	248.4	0.0053	0.78274	0.36332	0.70399	0.94188
Day 1-42	Day-hour	Average BW	10.7359	10.8382	10.5615	9.4378	0.6928	264.6	266.5	0.032	0.43995	0.1704	0.34778	0.8685
Day 42-77	Day-hour	Average BW	10.4568	10.2304	10.0394	9.8004	0.5674	248.6	250.6	0.008	0.83788	0.36543	0.99044	0.97195
Day 77-106	Day-hour	Average BW	9.6821	8.9911	8.9342	9.458	0.5355	253.2	255.2	0.018	0.61448	0.74409	0.21456	0.98026
Overall	Full	.	10.4299	9.9356	9.8245	9.6441	0.5142	244.1	246.1	.	0.67234	0.25664	0.7434	0.83104
Day 1-42	Full	.	10.7611	10.9979	10.47	9.278	0.7074	259.2	261.1	.	0.30453	0.10696	0.28391	0.97211
Day 42-77	Full	.	10.5789	10.1822	10.0804	9.7293	0.5969	245.7	247.7	.	0.74546	0.28817	0.96736	0.82767
Day 77-106	Full	.	9.8048	9.0133	8.8916	9.2572	0.5525	250.2	252.2	.	0.5435	0.44173	0.25641	0.93526
Overall	Full	Initial BW	10.4017	9.984	9.7847	9.7561	0.4944	246.4	248.4	0.0168	0.71807	0.30587	0.67194	0.9814
Day 1-42	Full	Initial BW	10.7641	10.9835	10.6054	9.4699	0.6846	261.7	263.6	0.0258	0.38449	0.15216	0.29033	0.95401
Day 42-77	Full	Initial BW	10.5278	10.2101	10.0279	9.8171	0.582	249.7	251.6	0.0491	0.80567	0.34092	0.92142	0.94626
Day 77-106	Full	Initial BW	9.7679	9.0798	8.8052	9.3814	0.5387	253.7	255.7	0.0363	0.51036	0.51962	0.20215	0.84224
Overall	Full	Average BW	10.3522	9.8818	9.8829	9.8011	0.487	244.8	246.8	0.0059	0.8028	0.42306	0.66696	0.78139
Day 1-42	Full	Average BW	10.7828	10.8856	10.6151	9.4888	0.6937	262.8	264.7	0.0451	0.44089	0.1681	0.34279	0.86358
Day 42-77	Full	Average BW	10.4596	10.1369	10.1307	9.8421	0.5654	247	249	0.0089	0.87061	0.43304	0.97417	0.79984
Day 77-106	Full	Average BW	9.6803	8.9576	8.9199	9.4448	0.5336	252.7	254.7	0.0153	0.5912	0.73815	0.20172	0.9545
Ym, %														
Overall	Beck	.	5.3192	4.7327	5.4014	5.5497	0.2644	168.8	170.9	.	0.10725	0.22247	0.13584	0.10228
Day 1-42	Beck	.	5.3198	5.0689	5.4262	5.1484	0.3377	184.5	186.4	.	0.84206	0.91461	0.96616	0.36795
Day 42-77	Beck	.	5.3549	4.6805	5.4194	5.6145	0.2997	171.8	173.8	.	0.12618	0.22262	0.119	0.11584
Day 77-106	Beck	.	5.2063	4.5595	5.4134	5.721	0.354	200.3	202.4	.	0.09297	0.10542	0.14374	0.15532
Overall	Beck	Initial BW	5.3159	4.7378	5.3972	5.561	0.2673	178.1	180.1	0.6353	0.11219	0.21526	0.13512	0.11427
Day 1-42	Beck	Initial BW	5.3211	5.0659	5.4607	5.1955	0.3397	192.3	194.2	0.2776	0.82028	0.9901	0.98739	0.34268
Day 42-77	Beck	Initial BW	5.3503	4.6831	5.4146	5.6215	0.303	181	182.9	0.7452	0.13238	0.21948	0.1204	0.12665
Day 77-106	Beck	Initial BW	5.2041	4.5637	5.408	5.7287	0.3591	209.1	211.1	0.8423	0.098	0.10641	0.14502	0.17054
Overall	Beck	Average BW	5.3185	4.7322	5.4019	5.5511	0.2683	178.6	180.6	0.9608	0.11362	0.22855	0.1392	0.10529
Day 1-42	Beck	Average BW	5.3233	5.0513	5.4497	5.1821	0.3437	193.2	195.1	0.5262	0.81734	0.98636	0.99463	0.33909

Day 42-77	Beck	Average BW	5.3515	4.6792	5.4204	5.6173	0.3032	181.4	183.4	0.8916	0.13109	0.22416	0.12263	0.11923
Day 77-106	Beck	Average BW	5.2292	4.5697	5.409	5.6876	0.3592	209.2	211.2	0.5047	0.1158	0.14282	0.15291	0.15498
Overall	Day-hour	.	5.1428	4.6277	5.248	5.3	0.2622	169.5	171.5	.	0.207	0.32334	0.24842	0.1197
Day 1-42	Day-hour	.	5.3175	5.0484	5.3612	5.0081	0.3369	185.6	187.5	.	0.80717	0.67542	0.89524	0.36905
Day 42-77	Day-hour	.	5.0982	4.5957	5.2747	5.3262	0.2954	172.5	174.5	.	0.26832	0.27082	0.31795	0.14822
Day 77-106	Day-hour	.	5.0111	4.3949	5.3279	5.4424	0.3513	199.6	201.6	.	0.10911	0.12957	0.25882	0.10038
Overall	Day-hour	Initial BW	5.1366	4.6363	5.2422	5.3231	0.2644	178.3	180.3	0.4061	0.21104	0.29504	0.23861	0.13827
Day 1-42	Day-hour	Initial BW	5.3184	5.045	5.3999	5.0598	0.3383	193.2	195.1	0.2386	0.80218	0.77492	0.91655	0.33977
Day 42-77	Day-hour	Initial BW	5.0882	4.5993	5.2665	5.3423	0.2982	181.4	183.3	0.5315	0.27311	0.25286	0.31187	0.16605
Day 77-106	Day-hour	Initial BW	5.0074	4.4017	5.3195	5.4551	0.3562	208.3	210.3	0.7438	0.11609	0.12794	0.25655	0.11534
Overall	Day-hour	Average BW	5.1347	4.6221	5.2545	5.3177	0.266	179	181	0.5976	0.19797	0.29431	0.24461	0.11995
Day 1-42	Day-hour	Average BW	5.3214	5.0277	5.3892	5.0474	0.3426	194.2	196.1	0.4656	0.79299	0.75752	0.94037	0.33368
Day 42-77	Day-hour	Average BW	5.082	4.5894	5.2806	5.3425	0.2981	181.7	183.7	0.5208	0.25574	0.24157	0.32033	0.14963
Day 77-106	Day-hour	Average BW	5.0235	4.4004	5.3249	5.4237	0.3576	208.8	210.8	0.7126	0.12713	0.15788	0.2687	0.1023
Overall	Full	.	5.1421	4.6011	5.3041	5.3319	0.259	167.3	169.3	.	0.13008	0.24582	0.24138	0.07655
Day 1-42	Full	.	5.3437	5.0732	5.3973	5.0507	0.339	184.1	186.1	.	0.80782	0.70424	0.90467	0.36108
Day 42-77	Full	.	5.0871	4.5626	5.3353	5.3429	0.2945	170.8	172.8	.	0.18636	0.21187	0.33498	0.09869
Day 77-106	Full	.	5.0119	4.3791	5.3164	5.4346	0.3494	198.9	200.9	.	0.10439	0.13134	0.24429	0.09657
Overall	Full	Initial BW	5.1375	4.6091	5.2975	5.3504	0.261	176.2	178.2	0.4454	0.13554	0.2291	0.23346	0.0893
Day 1-42	Full	Initial BW	5.3443	5.0701	5.426	5.0914	0.3417	192.2	194.1	0.3339	0.80537	0.78404	0.92433	0.34141
Day 42-77	Full	Initial BW	5.0786	4.5672	5.3266	5.3575	0.2969	179.7	181.7	0.5144	0.19286	0.19955	0.32875	0.11222
Day 77-106	Full	Initial BW	5.0077	4.3867	5.3066	5.4488	0.3542	207.6	209.6	0.7116	0.11138	0.12891	0.24109	0.11241
Overall	Full	Average BW	5.1353	4.5964	5.3092	5.3456	0.2625	176.8	178.8	0.6445	0.12663	0.22849	0.23965	0.07739
Day 1-42	Full	Average BW	5.3465	5.0587	5.4161	5.078	0.3452	193	194.9	0.5954	0.79922	0.76291	0.93761	0.33935
Day 42-77	Full	Average BW	5.0733	4.5574	5.3411	5.356	0.2971	180.1	182.1	0.5529	0.17926	0.1925	0.33919	0.09982
Day 77-106	Full	Average BW	5.022	4.3836	5.3141	5.4193	0.3558	208.1	210.2	0.7606	0.12011	0.15653	0.25313	0.09869
Methane CO_2 equivalent, g/d														
Overall	Beck	.	5,428.31	5,142.48	5,030.69	5,044.95	259.17	940.30	942.30	.	0.58942	0.24789	0.53098	0.96364
Day 1-42	Beck	.	5,393.94	5,538.55	5,290.83	4,756.42	359.88	895.60	897.50	.	0.4175	0.1695	0.31789	0.94256
Day 42-77	Beck	.	5,603.63	5,253.76	5,153.65	5,127.09	295.31	902.40	904.40	.	0.52921	0.21228	0.55239	0.88441
Day 77-106	Beck	.	5,127.78	4,726.85	4,548.53	4,902.07	277.65	946.80	948.80	.	0.3782	0.45728	0.14066	0.78246
Overall	Beck	Initial BW	5,413.63	5,165.01	5,012.33	5,094.99	251.32	931.20	933.20	0.029	0.6078	0.29386	0.47446	0.89133
Day 1-42	Beck	Initial BW	5,396.84	5,531.93	5,367.65	4,861.39	347.06	885.20	887.10	0.0205	0.51577	0.24092	0.32423	0.97578
Day 42-77	Beck	Initial BW	5,578.89	5,267.72	5,127.92	5,164.57	289.67	894.70	896.60	0.0724	0.5636	0.24983	0.51388	0.9966
Day 77-106	Beck	Initial BW	5,110.65	4,758.80	4,507.43	4,961.19	271.83	938.30	940.40	0.0476	0.31773	0.53291	0.10728	0.58297
Overall	Beck	Average BW	5,391.02	5,117.43	5,055.10	5,112.98	249.04	930.20	932.30	0.0145	0.70059	0.39354	0.46928	0.92788
Day 1-42	Beck	Average BW	5,406.04	5,478.83	5,370.91	4,871.15	352.29	886.40	888.30	0.0388	0.58326	0.26348	0.38486	0.88232
Day 42-77	Beck	Average BW	5,547.28	5,233.10	5,169.49	5,173.64	283.21	892.70	894.70	0.0187	0.65177	0.3152	0.541	0.87476

Day 77-106	Beck	Average BW	5,071.48	4,701.90	4,559.45	4,984.25	271.35	938.20	940.20	0.0331	0.39742	0.72086	0.10996	0.75378
Overall	Day-hour	.	5,242.65	5,033.69	4,899.17	4,819.25	260.93	942.60	944.60	.	0.61351	0.20302	0.79064	0.98532
Day 1-42	Day-hour	.	5,389.94	5,516.18	5,228.74	4,628.48	357.10	896.10	898.10	.	0.28935	0.10299	0.28548	0.94517
Day 42-77	Day-hour	.	5,327.74	5,173.18	5,027.11	4,864.52	301.69	907.00	908.90	.	0.67697	0.22497	0.98864	0.98422
Day 77-106	Day-hour	.	4,933.02	4,551.47	4,480.68	4,666.13	278.30	947.20	949.20	.	0.56451	0.45045	0.26865	0.96143
Overall	Day-hour	Initial BW	5,225.09	5,058.09	4,882.75	4,884.73	250.85	932.40	934.40	0.0153	0.66481	0.25766	0.71641	0.85748
Day 1-42	Day-hour	Initial BW	5,391.88	5,509.05	5,310.14	4,737.53	343.18	885.40	887.30	0.0166	0.37379	0.15183	0.28752	0.96715
Day 42-77	Day-hour	Initial BW	5,296.64	5,184.37	5,001.64	4,914.33	294.88	898.60	900.60	0.0541	0.74385	0.28182	0.96377	0.89326
Day 77-106	Day-hour	Initial BW	4,914.84	4,584.82	4,439.82	4,728.11	271.77	938.40	940.40	0.0401	0.53272	0.53007	0.21533	0.82217
Overall	Day-hour	Average BW	5,201.69	5,005.07	4,932.21	4,909.27	247.11	930.70	932.70	0.0053	0.78274	0.36332	0.70399	0.94188
Day 1-42	Day-hour	Average BW	5,401.71	5,453.16	5,313.97	4,748.58	348.57	886.70	888.60	0.032	0.43995	0.1704	0.34778	0.8685
Day 42-77	Day-hour	Average BW	5,261.30	5,147.39	5,051.28	4,931.00	285.47	895.60	897.60	0.008	0.83788	0.36543	0.99044	0.97195
Day 77-106	Day-hour	Average BW	4,871.51	4,523.85	4,495.18	4,758.75	269.45	937.50	939.50	0.018	0.61448	0.74409	0.21456	0.98026
Overall	Full	.	5,247.73	4,999.04	4,943.16	4,852.35	258.71	940.80	942.80	.	0.67234	0.25664	0.7434	0.83104
Day 1-42	Full	.	5,414.37	5,533.55	5,267.93	4,668.15	355.93	893.70	895.60	.	0.30453	0.10696	0.28391	0.97211
Day 42-77	Full	.	5,322.71	5,123.13	5,071.88	4,895.24	300.31	905.10	907.10	.	0.74546	0.28817	0.96736	0.82767
Day 77-106	Full	.	4,933.23	4,535.00	4,473.74	4,657.70	278.00	947.00	949.00	.	0.5435	0.44173	0.25641	0.93526
Overall	Full	Initial BW	5,233.54	5,023.41	4,923.12	4,908.74	248.76	930.70	932.70	0.0168	0.71807	0.30587	0.67194	0.9814
Day 1-42	Full	Initial BW	5,415.90	5,526.31	5,336.04	4,764.75	344.46	883.80	885.70	0.0258	0.38449	0.15216	0.29033	0.95401
Day 42-77	Full	Initial BW	5,297.03	5,137.16	5,045.51	4,939.42	292.82	896.70	898.60	0.0491	0.80567	0.34092	0.92142	0.94626
Day 77-106	Full	Initial BW	4,914.68	4,568.45	4,430.31	4,720.20	271.03	938.00	940.00	0.0363	0.51036	0.51962	0.20215	0.84224
Overall	Full	Average BW	5,208.63	4,971.97	4,972.51	4,931.35	245.04	929.10	931.10	0.0059	0.8028	0.42306	0.66696	0.78139
Day 1-42	Full	Average BW	5,425.29	5,477.04	5,340.93	4,774.26	349.03	884.90	886.80	0.0451	0.44089	0.1681	0.34279	0.86358
Day 42-77	Full	Average BW	5,262.67	5,100.34	5,097.21	4,952.02	284.48	894.00	896.00	0.0089	0.87061	0.43304	0.97417	0.79984
Day 77-106	Full	Average BW	4,870.61	4,506.98	4,488.02	4,752.09	268.46	937.00	939.00	0.0153	0.5912	0.73815	0.20172	0.9545

Methane CO_2 equivalent total, g/d														
Overall	Beck	.	569,973.00	539,960.00	528,222.00	529,720.00	27,213.00	1,461.50	1,463.50	.	0.58942	0.24789	0.53098	0.96364
Day 1-42	Beck	.	221,152.00	227,080.00	216,924.00	195,013.00	14,755.00	1,274.30	1,276.30	.	0.4175	0.1695	0.31789	0.94256
Day 42-77	Beck	.	196,127.00	183,882.00	180,378.00	179,448.00	10,336.00	1,279.30	1,281.30	.	0.52921	0.21228	0.55239	0.88441
Day 77-106	Beck	.	148,706.00	137,079.00	131,907.00	142,160.00	8,051.88	1,323.90	1,326.00	.	0.3782	0.45728	0.14066	0.78246
Overall	Beck	Initial BW	568,431.00	542,326.00	526,295.00	534,974.00	26,388.00	1,443.10	1,445.10	0.029	0.6078	0.29386	0.47446	0.89133
Day 1-42	Beck	Initial BW	221,270.00	226,809.00	220,074.00	199,317.00	14,230.00	1,256.60	1,258.50	0.0205	0.51577	0.24092	0.32423	0.97578
Day 42-77	Beck	Initial BW	195,261.00	184,370.00	179,477.00	180,760.00	10,138.00	1,264.40	1,266.40	0.0724	0.5636	0.24983	0.51388	0.9966
Day 77-106	Beck	Initial BW	148,209.00	138,005.00	130,715.00	143,875.00	7,883.11	1,308.70	1,310.80	0.0476	0.31773	0.53291	0.10728	0.58297
Overall	Beck	Average BW	566,057.00	537,330.00	530,785.00	536,863.00	26,149.00	1,442.20	1,444.20	0.0145	0.70059	0.39354	0.46928	0.92788
Day 1-42	Beck	Average BW	221,648.00	224,632.00	220,207.00	199,717.00	14,444.00	1,257.80	1,259.70	0.0388	0.58326	0.26348	0.38486	0.88232
Day 42-77	Beck	Average BW	194,155.00	183,159.00	180,932.00	181,078.00	9,912.44	1,262.50	1,264.40	0.0187	0.65177	0.3152	0.541	0.87476
Day 77-106	Beck	Average BW	147,073.00	136,355.00	132,224.00	144,543.00	7,869.01	1,308.60	1,310.60	0.0331	0.39742	0.72086	0.10996	0.75378
Overall	Day-hour	.	550,478.00	528,538.00	514,413.00	506,022.00	27,398.00	1,463.90	1,465.90	.	0.61351	0.20302	0.79064	0.98532
Day 1-42	Day-hour	.	220,987.00	226,163.00	214,378.00	189,768.00	14,641.00	1,274.90	1,276.80	.	0.28935	0.10299	0.28548	0.94517
Day 42-77	Day-hour	.	186,471.00	181,061.00	175,949.00	170,258.00	10,559.00	1,283.80	1,285.80	.	0.67697	0.22497	0.98864	0.98422
Day 77-106	Day-hour	.	143,058.00	131,993.00	129,940.00	135,318.00	8,070.60	1,324.30	1,326.30	.	0.56451	0.45045	0.26865	0.96143
Overall	Day-hour	Initial BW	548,634.00	531,099.00	512,689.00	512,896.00	26,339.00	1,444.30	1,446.30	0.0153	0.66481	0.25766	0.71641	0.85748
Day 1-42	Day-hour	Initial BW	221,067.00	225,871.00	217,716.00	194,239.00	14,070.00	1,256.80	1,258.70	0.0166	0.37379	0.15183	0.28752	0.96715
Day 42-77	Day-hour	Initial BW	185,382.00	181,453.00	175,058.00	172,002.00	10,321.00	1,268.40	1,270.30	0.0541	0.74385	0.28182	0.96377	0.89326
Day 77-106	Day-hour	Initial BW	142,530.00	132,960.00	128,755.00	137,115.00	7,881.39	1,308.80	1,310.80	0.0401	0.53272	0.53007	0.21533	0.82217
Overall	Day-hour	Average BW	546,178.00	525,533.00	517,882.00	515,473.00	25,947.00	1,442.70	1,444.70	0.0053	0.78274	0.36332	0.70399	0.94188
Day 1-42	Day-hour	Average BW	221,470.00	223,580.00	217,873.00	194,692.00	14,291.00	1,258.00	1,259.90	0.032	0.43995	0.1704	0.34778	0.8685
Day 42-77	Day-hour	Average BW	184,146.00	180,159.00	176,795.00	172,585.00	9,991.47	1,265.40	1,267.30	0.008	0.83788	0.36543	0.99044	0.97195
Day 77-106	Day-hour	Average BW	141,274.00	131,192.00	130,360.00	138,004.00	7,814.19	1,307.90	1,309.90	0.018	0.61448	0.74409	0.21456	0.98026

Overall	Full	.	551,012.00	524,899.00	519,032.00	509,497.00	27,165.00	1,462.00	1,464.10	.	0.67234	0.25664	0.7434	0.83104
Day 1-42	Full	.	221,989.00	226,875.00	215,985.00	191,394.00	14,593.00	1,272.50	1,274.40	.	0.30453	0.10696	0.28391	0.97211
Day 42-77	Full	.	186,295.00	179,310.00	177,516.00	171,333.00	10,511.00	1,282.00	1,284.00	.	0.74546	0.28817	0.96736	0.82767
Day 77-106	Full	.	143,064.00	131,515.00	129,739.00	135,073.00	8,061.91	1,324.10	1,326.10	.	0.5435	0.44173	0.25641	0.93526
Overall	Full	Initial BW	549,521.00	527,459.00	516,927.00	515,417.00	26,119.00	1,442.70	1,444.70	0.0168	0.71807	0.30587	0.67194	0.9814
Day 1-42	Full	Initial BW	222,052.00	226,579.00	218,777.00	195,355.00	14,123.00	1,255.20	1,257.10	0.0258	0.38449	0.15216	0.29033	0.95401
Day 42-77	Full	Initial BW	185,396.00	179,801.00	176,593.00	172,880.00	10,249.00	1,266.40	1,268.40	0.0491	0.80567	0.34092	0.92142	0.94626
Day 77-106	Full	Initial BW	142,526.00	132,485.00	128,479.00	136,886.00	7,859.73	1,308.40	1,310.40	0.0363	0.51036	0.51962	0.20215	0.84224
Overall	Full	Average BW	546,906.00	522,057.00	522,113.00	517,791.00	25,729.00	1,441.10	1,443.10	0.0059	0.8028	0.42306	0.66696	0.78139
Day 1-42	Full	Average BW	222,437.00	224,559.00	218,978.00	195,745.00	14,310.00	1,256.20	1,258.10	0.0451	0.44089	0.1681	0.34279	0.86358
Day 42-77	Full	Average BW	184,194.00	178,512.00	178,402.00	173,321.00	9,956.79	1,263.80	1,265.70	0.0089	0.87061	0.43304	0.97417	0.79984
Day 77-106	Full	Average BW	141,248.00	130,703.00	130,153.00	137,811.00	7,785.22	1,307.40	1,309.40	0.0153	0.5912	0.73815	0.20172	0.9545

Appendix Table 3. Effects of covariance structure and baseline adjustment on repeated-measures analysis of meal behavior in finishing heifers

Item	SAS	Cov	DynOmik, g/d				SEM	AIC	BIC	*P*-value						
			0	2.5	5	7.5				Cov	Trt	Day	Trt x Day	Linear	Quadratic	Cubic
Meals, d^{-1}																
Overall	ANTE 1	Baseline	6.9596	6.9544	7.1104	7.3759	0.1787	326.8	337.3	<.0001	0.145	<.0001	0.2662	0.033	0.3467	0.936
Day 1-42	ANTE 1	Baseline	7.8449	7.7795	7.8608	8.3282										
Day 42-77	ANTE 1	Baseline	6.5819	6.6008	6.9783	7.0407										
Day 77-106	ANTE 1	Baseline	6.4519	6.483	6.4921	6.7587										
Overall	ANTE 1	.	7.0184	7.187	6.9951	7.1998	0.2917	376.6	387.1	.	0.889	<.0001	0.1958	0.74	0.9391	0.476
Day 1-42	ANTE 1	.	7.9038	8.012	7.7455	8.1522										
Day 42-77	ANTE 1	.	6.6407	6.8333	6.863	6.8646										
Day 77-106	ANTE 1	.	6.5107	6.7155	6.3767	6.5826										
Overall	SPPOW	Baseline	6.9606	6.9584	7.1085	7.3729	0.1723	321.5	325.6	<.0001	0.155	<.0001	0.265	0.036	0.3555	0.953
Day 1-42	SPPOW	Baseline	7.8459	7.7834	7.8589	8.3253										
Day 42-77	SPPOW	Baseline	6.5829	6.6047	6.9764	7.0377										
Day 77-106	SPPOW	Baseline	6.4529	6.4869	6.4901	6.7557										
Overall	SPPOW	.	7.0184	7.187	6.9951	7.1998	0.2609	379.1	383.3	.	0.896	<.0001	0.2344	0.746	0.9406	0.487
Day 1-42	SPPOW	.	7.9038	8.012	7.7455	8.1522										
Day 42-77	SPPOW	.	6.6407	6.8333	6.863	6.8646										
Day 77-106	SPPOW	.	6.5107	6.7155	6.3767	6.5826										
Meal size, kg/meal																
Overall	ANTE 1	Baseline	1.7415	1.8511	1.5672	1.5912	0.05877	-108.7	-98.3	<.0001	<.0001	<.0001	<.0001	5E-04	0.3386	9E-04
Day 1-42	ANTE 1	Baseline	1.5471	1.6732	1.5166	1.4733										
Day 42-77	ANTE 1	Baseline	1.876	2.0101	1.6069	1.6644										
Day 77-106	ANTE 1	Baseline	1.8013	1.8699	1.578	1.636										
Overall	ANTE 1	.	1.7607	1.8252	1.6175	1.5476	0.07939	-55.1	-44.6	.	0.028	<.0001	<.0001	0.01	0.3463	0.2
Day 1-42	ANTE 1	.	1.5664	1.6474	1.5669	1.4297										
Day 42-77	ANTE 1	.	1.8952	1.9842	1.6572	1.6207										
Day 77-106	ANTE 1	.	1.8205	1.844	1.6283	1.5923										
Overall	SPPOW	Baseline	1.741	1.8517	1.566	1.5923	0.05123	-103.3	-99.1	<.0001	<.0001	<.0001	0.0002	4E-04	0.3414	7E-04
Day 1-42	SPPOW	Baseline	1.5467	1.6738	1.5154	1.4744										
Day 42-77	SPPOW	Baseline	1.8755	2.0107	1.6057	1.6654										
Day 77-106	SPPOW	Baseline	1.8008	1.8705	1.5768	1.637										
Overall	SPPOW	.	1.7607	1.8252	1.6175	1.5476	0.07417	-52.8	-48.6	.	0.024	<.0001	0.0002	0.008	0.3362	0.191
Day 1-42	SPPOW	.	1.5664	1.6474	1.5669	1.4297										
Day 42-77	SPPOW	.	1.8952	1.9842	1.6572	1.6207										
Day 77-106	SPPOW	.	1.8205	1.844	1.6283	1.5923										
Maximum meal size, kg																
Overall	ANTE 1	Baseline	3.2076	3.3112	2.9199	2.9274	0.1032	93.7	104.2	<.0001	0.001	<.0001	0.1167	0.001	0.5546	0.017
Day 1-42	ANTE 1	Baseline	3.0193	3.169	2.9128	2.7175										
Day 42-77	ANTE 1	Baseline	3.3703	3.4467	2.9635	3.089										
Day 77-106	ANTE 1	Baseline	3.2334	3.318	2.8836	2.9756										
Overall	ANTE 1	.	3.2351	3.3354	2.8436	2.952	0.1255	130.4	140.9	.	0.006	<.0001	0.1137	0.007	0.9699	0.017
Day 1-42	ANTE 1	.	3.0468	3.1932	2.8364	2.7421										
Day 42-77	ANTE 1	.	3.3978	3.4709	2.8871	3.1137										
Day 77-106	ANTE 1	.	3.2609	3.3422	2.8072	3.0003										

Overall	SPPOW	Baseline	3.2081	3.3116	2.9188	2.9277	0.09303	95.2	99.3	<.0001	0.001	<.0001	0.0614	0.001	0.5578	0.015
Day 1-42	SPPOW	Baseline	3.0197	3.1694	2.9116	2.7178										
Day 42-77	SPPOW	Baseline	3.3707	3.447	2.9623	3.0894										
Day 77-106	SPPOW	Baseline	3.2338	3.3183	2.8825	2.976										
Overall	SPPOW	.	3.2351	3.3354	2.8436	2.952	0.1176	128.1	132.3	.	0.006	<.0001	0.0635	0.007	0.9698	0.016
Day 1-42	SPPOW	.	3.0468	3.1932	2.8364	2.7421										
Day 42-77	SPPOW	.	3.3978	3.4709	2.8871	3.1137										
Day 77-106	SPPOW	.	3.2609	3.3422	2.8072	3.0003										
Minimum meal size, kg																
Overall	ANTE 1	Baseline	0.634	0.6409	0.5955	0.5698	0.04428	-173.4	-163	<.0001	0.402	<.0001	0.001	0.12	0.6293	0.637
Day 1-42	ANTE 1	Baseline	0.5095	0.5067	0.5559	0.5284										
Day 42-77	ANTE 1	Baseline	0.725	0.7279	0.6198	0.5959										
Day 77-106	ANTE 1	Baseline	0.6676	0.6879	0.6108	0.585										
Overall	ANTE 1	.	0.6459	0.6372	0.618	0.5391	0.04858	-157.5	-147	.	0.209	<.0001	0.001	0.057	0.3714	0.78
Day 1-42	ANTE 1	.	0.5213	0.5031	0.5784	0.4977										
Day 42-77	ANTE 1	.	0.7369	0.7243	0.6423	0.5652										
Day 77-106	ANTE 1	.	0.6794	0.6843	0.6333	0.5543										
Overall	SPPOW	Baseline	0.6335	0.641	0.5946	0.5711	0.04013	-167.3	-163.1	<.0001	0.395	<.0001	0.0067	0.119	0.6395	0.606
Day 1-42	SPPOW	Baseline	0.509	0.5069	0.5549	0.5298										
Day 42-77	SPPOW	Baseline	0.7245	0.7281	0.6189	0.5972										
Day 77-106	SPPOW	Baseline	0.6671	0.6881	0.6099	0.5863										
Overall	SPPOW	.	0.6459	0.6372	0.618	0.5391	0.04407	-151.5	-147.3	.	0.186	<.0001	0.0064	0.049	0.3565	0.773
Day 1-42	SPPOW	.	0.5213	0.5031	0.5784	0.4977										
Day 42-77	SPPOW	.	0.7369	0.7243	0.6423	0.5652										
Day 77-106	SPPOW	.	0.6794	0.6843	0.6333	0.5543										
Meal duration, min/meal																
Overall	ANTE 1	Baseline	17.143	19.086	18.013	16.466	0.8505	822.5	833	<.0001	0.039	0.009	0.0674	0.31	0.0095	0.386
Day 1-42	ANTE 1	Baseline	16.601	17.99	17.758	15.639										
Day 42-77	ANTE 1	Baseline	17.577	20.458	17.835	16.43										
Day 77-106	ANTE 1	Baseline	17.251	18.809	18.447	17.328										
Overall	ANTE 1	.	17.801	19.488	17.715	15.703	0.906	846.3	856.8	.	0.009	0.01	0.0531	0.019	0.0166	0.34
Day 1-42	ANTE 1	.	17.259	18.392	17.46	14.876										
Day 42-77	ANTE 1	.	18.235	20.861	17.537	15.668										
Day 77-106	ANTE 1	.	17.909	19.212	18.149	16.566										
Overall	SPPOW	Baseline	17.21	19.126	17.983	16.389	0.7728	824.6	828.8	<.0001	0.025	0.007	0.0445	0.228	0.0072	0.359
Day 1-42	SPPOW	Baseline	16.668	18.03	17.728	15.562										
Day 42-77	SPPOW	Baseline	17.643	20.499	17.805	16.353										
Day 77-106	SPPOW	Baseline	17.318	18.85	18.417	17.251										
Overall	SPPOW	.	17.801	19.488	17.715	15.703	0.8569	842.4	846.6	.	0.008	0.008	0.0425	0.018	0.0152	0.334
Day 1-42	SPPOW	.	17.259	18.392	17.46	14.876										
Day 42-77	SPPOW	.	18.235	20.861	17.537	15.668										
Day 77-106	SPPOW	.	17.909	19.212	18.149	16.566										
Total duration, min/d																
Overall	ANTE 1	Baseline	114.09	128.94	120.74	113.34	5.3816	1469	1479	<.0001	0.027	<.0001	0.3057	0.587	0.0061	0.18
Day 1-42	ANTE 1	Baseline	125.12	134.14	130.95	120.76										
Day 42-77	ANTE 1	Baseline	110.46	132.37	118.18	108.71										
Day 77-106	ANTE 1	Baseline	106.7	120.29	113.09	110.55										
Overall	ANTE 1	.	118.22	134.55	117.73	106.6	5.8167	1487	1498	.	6E-04	<.0001	0.2756	0.012	0.0031	0.056

Day 1-42	ANTE 1	.	129.25	139.76	127.95	114.02										
Day 42-77	ANTE 1	.	114.59	137.99	115.17	101.97										
Day 77-106	ANTE 1	.	110.83	125.91	110.09	103.81										
Overall	SPPOW	Baseline	114.22	129.1	120.65	113.14	5.0255	1466	1470	<.0001	0.022	<.0001	0.2778	0.539	0.0052	0.167
Day 1-42	SPPOW	Baseline	125.24	134.31	130.86	120.56										
Day 42-77	SPPOW	Baseline	110.58	132.54	118.09	108.51										
Day 77-106	SPPOW	Baseline	106.82	120.46	113	110.35										
Overall	SPPOW	.	118.22	134.55	117.73	106.6	5.4081	1483	1487	.	6E-04	<.0001	0.2753	0.012	0.0032	0.057
Day 1-42	SPPOW	.	129.25	139.76	127.95	114.02										
Day 42-77	SPPOW	.	114.59	137.99	115.17	101.97										
Day 77-106	SPPOW	.	110.83	125.91	110.09	103.81										
Eating time, min/meal																
Overall	ANTE 1	Baseline	11.876	14.855	12.953	9.7974	0.8178	820	830.5	<.0001	<.0001	0.383	0.0034	0.006	<.0001	0.198
Day 1-42	ANTE 1	Baseline	11.986	13.822	13.649	10.115										
Day 42-77	ANTE 1	Baseline	11.893	16.468	12.501	9.469										
Day 77-106	ANTE 1	Baseline	11.749	14.275	12.71	9.8084										
Overall	ANTE 1	.	12.207	15.035	12.882	9.3573	0.8318	832.8	843.3	.	<.0001	0.374	0.0022	7E-04	<.0001	0.234
Day 1-42	ANTE 1	.	12.317	14.002	13.577	9.6746										
Day 42-77	ANTE 1	.	12.224	16.649	12.43	9.0289										
Day 77-106	ANTE 1	.	12.08	14.455	12.639	9.3683										
Overall	SPPOW	Baseline	11.908	14.872	12.946	9.755	0.7464	819.5	823.7	4E-04	<.0001	0.392	0.001	0.004	<.0001	0.186
Day 1-42	SPPOW	Baseline	12.018	13.839	13.642	10.072										
Day 42-77	SPPOW	Baseline	11.925	16.486	12.494	9.4266										
Day 77-106	SPPOW	Baseline	11.781	14.292	12.703	9.766										
Overall	SPPOW	.	12.207	15.035	12.882	9.3573	0.7893	829.1	833.3	.	<.0001	0.394	0.001	6E-04	<.0001	0.228
Day 1-42	SPPOW	.	12.317	14.002	13.577	9.6746										
Day 42-77	SPPOW	.	12.224	16.649	12.43	9.0289										
Day 77-106	SPPOW	.	12.08	14.455	12.639	9.3683										
Total eating time, min/d																
Overall	ANTE 1	Baseline	78.55	100.59	87.098	69.539	5.1396	1460	1471	<.0001	<.0001	<.0001	0.0212	0.028	<.0001	0.064
Day 1-42	ANTE 1	Baseline	89.096	102.65	100.03	79.347										
Day 42-77	ANTE 1	Baseline	74.408	107.54	83.375	64.649										
Day 77-106	ANTE 1	Baseline	72.146	91.568	77.893	64.62										
Overall	ANTE 1	.	81.589	104.35	85.389	64.446	5.1688	1474	1484	.	<.0001	<.0001	0.0168	3E-04	<.0001	0.034
Day 1-42	ANTE 1	.	92.135	106.41	98.318	74.254										
Day 42-77	ANTE 1	.	77.447	111.31	81.666	59.556										
Day 77-106	ANTE 1	.	75.185	95.33	76.184	59.527										
Overall	SPPOW	Baseline	78.673	100.74	87.029	69.333	4.8057	1456	1460	<.0001	<.0001	<.0001	0.0112	0.021	<.0001	0.056
Day 1-42	SPPOW	Baseline	89.218	102.8	99.958	79.141										
Day 42-77	SPPOW	Baseline	74.531	107.7	83.306	64.443										
Day 77-106	SPPOW	Baseline	72.269	91.72	77.824	64.415										
Overall	SPPOW	.	81.589	104.35	85.389	64.446	5.0367	1469	1473	.	<.0001	<.0001	0.0109	3E-04	<.0001	0.033
Day 1-42	SPPOW	.	92.135	106.41	98.318	74.254										
Day 42-77	SPPOW	.	77.447	111.31	81.666	59.556										
Day 77-106	SPPOW	.	75.185	95.33	76.184	59.527										
Visits per meal																
Overall	ANTE 1	Baseline	3.9777	3.6643	3.7784	4.0015	0.2578	377.2	387.7	<.0001	0.514	1E-04	0.3626	0.824	0.1517	0.701
Day 1-42	ANTE 1	Baseline	3.7436	3.5502	3.4191	3.5489										

Day 42-77	ANTE 1	Baseline	4.2013	3.7218	3.9925	4.1242										
Day 77-106	ANTE 1	Baseline	3.9881	3.7209	3.9237	4.3312										
Overall	ANTE 1	.	3.8501	3.6119	3.9055	4.0543	0.2745	420.6	431	.	0.643	1E-04	0.3499	0.412	0.4334	0.54
Day 1-42	ANTE 1	.	3.6161	3.4978	3.5462	3.6017										
Day 42-77	ANTE 1	.	4.0738	3.6694	4.1196	4.1771										
Day 77-106	ANTE 1	.	3.8606	3.6685	4.0508	4.3841										
Overall	SPPOW	Baseline	3.9582	3.6563	3.7978	4.0095	0.2163	386.6	390.8	<.0001	0.522	<.0001	0.345	0.723	0.1692	0.653
Day 1-42	SPPOW	Baseline	3.7241	3.5422	3.4385	3.557										
Day 42-77	SPPOW	Baseline	4.1818	3.7138	4.0119	4.1323										
Day 77-106	SPPOW	Baseline	3.9686	3.7129	3.9431	4.3393										
Overall	SPPOW	.	3.8501	3.6119	3.9055	4.0543	0.27	417.6	421.8	.	0.641	<.0001	0.3634	0.411	0.4322	0.539
Day 1-42	SPPOW	.	3.6161	3.4978	3.5462	3.6017										
Day 42-77	SPPOW	.	4.0738	3.6694	4.1196	4.1771										
Day 77-106	SPPOW	.	3.8606	3.6685	4.0508	4.3841										
Day visits, d^{-1}																
Overall	ANTE 1	Baseline	24.174	22.213	23.798	24.772	1.4657	996.2	1007	<.0001	0.415	<.0001	0.3897	0.5	0.1923	0.408
Day 1-42	ANTE 1	Baseline	26.691	24.935	25.136	26.538										
Day 42-77	ANTE 1	Baseline	24.045	21.265	24.3	24.051										
Day 77-106	ANTE 1	Baseline	21.787	20.438	21.958	23.727										
Overall	ANTE 1	.	23.55	22.747	23.631	25.028	1.8771	1031	1041	.	0.761	<.0001	0.3843	0.437	0.4719	0.863
Day 1-42	ANTE 1	.	26.066	25.469	24.969	26.795										
Day 42-77	ANTE 1	.	23.42	21.8	24.133	24.307										
Day 77-106	ANTE 1	.	21.162	20.973	21.792	23.983										
Overall	SPPOW	Baseline	24.141	22.241	23.789	24.786	1.3447	1005	1009	<.0001	0.449	<.0001	0.4913	0.498	0.2096	0.438
Day 1-42	SPPOW	Baseline	26.658	24.963	25.127	26.552										
Day 42-77	SPPOW	Baseline	24.012	21.294	24.291	24.064										
Day 77-106	SPPOW	Baseline	21.754	20.466	21.949	23.741										
Overall	SPPOW	.	23.55	22.747	23.631	25.028	1.7255	1039	1043	.	0.778	<.0001	0.4779	0.451	0.4858	0.868
Day 1-42	SPPOW	.	26.066	25.469	24.969	26.795										
Day 42-77	SPPOW	.	23.42	21.8	24.133	24.307										
Day 77-106	SPPOW	.	21.162	20.973	21.792	23.983										
Night visits, d^{-1}																
Overall	ANTE 1	Baseline	2.3582	2.1568	2.6214	3.3355	0.4365	524.4	534.9	<.0001	0.081	<.0001	0.0609	0.025	0.1908	0.783
Day 1-42	ANTE 1	Baseline	1.499	1.3424	1.6764	2.1718										
Day 42-77	ANTE 1	Baseline	2.6393	2.0787	3.1033	3.6271										
Day 77-106	ANTE 1	Baseline	2.9364	3.0493	3.0845	4.2076										
Overall	ANTE 1	.	2.2764	2.2058	3.0829	2.9068	0.4664	539.6	550.1	.	0.267	<.0001	0.0624	0.109	0.89	0.244
Day 1-42	ANTE 1	.	1.4172	1.3914	2.1379	1.7431										
Day 42-77	ANTE 1	.	2.5574	2.1278	3.5648	3.1984										
Day 77-106	ANTE 1	.	2.8545	3.0983	3.546	3.7788										
Overall	SPPOW	Baseline	2.3694	2.1501	2.5584	3.394	0.3815	541.9	546.1	<.0001	0.056	<.0001	0.0891	0.019	0.1321	0.893
Day 1-42	SPPOW	Baseline	1.5102	1.3357	1.6134	2.2303										
Day 42-77	SPPOW	Baseline	2.6504	2.0721	3.0403	3.6856										
Day 77-106	SPPOW	Baseline	2.9475	3.0426	3.0215	4.266										
Overall	SPPOW	.	2.2764	2.2058	3.0829	2.9068	0.4067	556.3	560.5	.	0.24	<.0001	0.0853	0.098	0.8864	0.229
Day 1-42	SPPOW	.	1.4172	1.3914	2.1379	1.7431										
Day 42-77	SPPOW	.	2.5574	2.1278	3.5648	3.1984										
Day 77-106	SPPOW	.	2.8545	3.0983	3.546	3.7788										
Eating rate, g/min																
Overall	ANTE 1	Baseline	187.73	171.77	159.92	174.85	7.8606	1514	1525	<.0001	0.003	<.0001	0.0347	0.033	0.0048	0.311

Day 1-42	ANTE 1	Baseline	174.97	169.34	153.65	156.48										
Day 42-77	ANTE 1	Baseline	196.34	173.5	163.33	184.42										
Day 77-106	ANTE 1	Baseline	191.88	172.45	162.77	183.64										
Overall	ANTE 1	.	185.36	160.8	149.99	198.11	9.6971	1579	1590	.	3E-04	<.0001	0.0348	0.455	<.0001	0.22
Day 1-42	ANTE 1	.	172.6	158.37	143.72	179.74										
Day 42-77	ANTE 1	.	193.97	162.54	153.41	207.68										
Day 77-106	ANTE 1	.	189.52	161.49	152.84	206.9										
Overall	SPPOW	Baseline	187.67	171.47	159.65	175.47	6.5442	1527	1532	<.0001	0.003	<.0001	0.0635	0.047	0.0049	0.309
Day 1-42	SPPOW	Baseline	174.91	169.05	153.39	157.1										
Day 42-77	SPPOW	Baseline	196.28	173.21	163.07	185.04										
Day 77-106	SPPOW	Baseline	191.82	172.16	162.5	184.26										
Overall	SPPOW	.	185.36	160.8	149.99	198.11	8.8639	1579	1583	.	3E-04	<.0001	0.0679	0.453	<.0001	0.219
Day 1-42	SPPOW	.	172.6	158.37	143.72	179.74										
Day 42-77	SPPOW	.	193.97	162.54	153.41	207.68										
Day 77-106	SPPOW	.	189.52	161.49	152.84	206.9										

Appendix Table 4. Ruminal fermentation, digestibility, and rumen pH responses of finishing heifers analyzed using alternative covariance structures with or without day 0 baseline covariates.

			DynOmik, g/d							*P*-value						
Item	SAS	Cov	0	2.5	5	7.5	SEM	AIC	BIC	Cov	Trt	Day	Trt x Day	Linear	Quadratic	Cubic
Acetate, mM																
Overall	ANTE 1	.	105.606	103.432	105.129	103.27	8.6276	1554	1564	.	0.978	0.009	0.5999	0.798	0.9729	0.721
Day 42			98.6073	86.56	93.7469	98.5025										
Day 77			110.772	110.059	101.947	101.163										
Day 105			107.437	113.676	119.694	110.145										
Overall	ANTE 1	D0	103.945	103.056	106.645	103.877	8.4763	1551	1561	0.015	0.947	0.009	0.5978	0.868	0.8343	0.59
Day 42			96.9466	86.2189	95.2942	99.1474										
Day 77			109.111	109.666	103.447	101.755										
Day 105			105.777	113.283	121.194	110.728										
Overall	SPPOW	.	105.606	103.436	105.128	103.255	7.9187	1551	1556	.	0.975	0.004	0.6215	0.789	0.9736	0.712
Day 42			98.6073	86.573	93.7416	98.4986										
Day 77			110.772	110.059	101.947	101.163										
Day 105			107.437	113.676	119.694	110.102										
Overall	SPPOW	D0	104.068	103.018	106.559	103.816	7.8072	1549	1553	0.017	0.944	0.004	0.6151	0.886	0.844	0.573
Day 42			97.0693	86.0479	95.2571	99.1543										
Day 77			109.234	109.695	103.336	101.711										
Day 105			105.899	113.312	121.083	110.581										
Propionate, mM																
Overall	ANTE 1	.	50.4711	50.1551	55.1139	54.6633	7.8461	1463	1473	.	0.795	<.0001	0.5471	0.388	0.9882	0.602
Day 42			41.6333	35.3281	41.6165	49.7179										
Day 77			56.0633	58.5957	57.09	57.22										
Day 105			53.7167	56.5414	66.6353	57.0518										
Overall	ANTE 1	D0	50.4518	50.6439	54.9268	54.4968	7.478	1450	1460	<.0001	0.791	<.0001	0.5169	0.372	0.9397	0.634

Day 42			41.614	36.0016	40.8116	49.6596										
Day 77			56.044	58.9922	57.2117	57.1623										
Day 105			53.6973	56.9379	66.7571	56.6684										
Overall	SPPOW	.	50.4711	50.197	55.045	54.6381	6.5514	1467	1471	.	0.804	1E-04	0.5855	0.394	0.9884	0.614
Day 42			41.6333	35.4539	41.4096	49.8503										
Day 77			56.0633	58.5957	57.09	57.22										
Day 105			53.7167	56.5414	66.6353	56.8441										
Overall	SPPOW	D0	50.5571	50.7772	52.7887	54.4955	5.7366	1422	1426	<.0001	0.876	<.0001	0.7672	0.426	0.8488	0.905
Day 42			41.7193	36.0817	41.0358	49.6568										
Day 77			56.1493	59.1521	57.3355	57.2626										
Day 105			53.8026	57.0978	59.9947	56.5671										
Isobutyrate, mM																
Overall	ANTE 1	.	2.1153	1.991	1.9532	2.1587	0.2268	343	353.4	.	0.562	<.0001	0.4579	0.861	0.1674	0.768
Day 42			1.8813	1.4008	1.4748	1.8141										
Day 77			2.4993	2.3471	2.228	2.4753										
Day 105			1.9653	2.225	2.1567	2.1867										
Overall	ANTE 1	D0	2.1154	1.9985	1.9542	2.149	0.2276	345.4	355.8	0.551	0.615	<.0001	0.4585	0.916	0.1976	0.756
Day 42			1.8814	1.4088	1.4751	1.8051										
Day 77			2.4994	2.3544	2.2294	2.464										
Day 105			1.9654	2.2323	2.1581	2.178										
Overall	SPPOW	.	2.1153	1.9935	1.9561	2.1555	0.1848	349.3	353.4	.	0.595	<.0001	0.4237	0.877	0.1854	0.778
Day 42			1.8813	1.4084	1.4837	1.8045										
Day 77			2.4993	2.3471	2.228	2.4753										
Day 105			1.9653	2.225	2.1567	2.1867										
Overall	SPPOW	D0	2.1154	2.0018	1.9572	2.1453	0.186	351.5	355.7	0.538	0.651	<.0001	0.4255	0.934	0.2201	0.764
Day 42			1.8814	1.4174	1.4838	1.7954										
Day 77			2.4994	2.355	2.2295	2.4631										
Day 105			1.9654	2.2329	2.1582	2.1773										
Butyrate, mM																

Overall	ANTE 1	.	20.2576	18.7652	18.947	18.1483	2.4812	1153	1163	.	0.77	0.001	0.8601	0.348	0.8128	0.687
Day 42			18.1927	13.6507	15.7522	15.4131										
Day 77			21.9893	20.9021	19.476	19.0393										
Day 105			20.5907	21.7429	21.6127	19.9925										
Overall	ANTE 1	D0	18.8346	18.431	19.8961	19.0231	2.4076	1140	1150	1E-04	0.887	0.001	0.828	0.743	0.8591	0.478
Day 42			16.7697	13.2404	16.7321	16.4314										
Day 77			20.5664	20.6059	20.4098	19.7965										
Day 105			19.1677	21.4466	22.5465	20.8414										
Overall	SPPOW	.	20.2576	17.99	18.8994	18.1532	2.2418	1128	1132	.	0.597	2E-04	0.5294	0.358	0.5641	0.416
Day 42			18.1927	11.3249	15.6096	15.4483										
Day 77			21.9893	20.9021	19.476	19.0393										
Day 105			20.5907	21.7429	21.6127	19.9721										
Overall	SPPOW	D0	18.9256	17.6623	19.7719	18.9835	2.1226	1115	1120	<.0001	0.643	1E-04	0.4541	0.672	0.8366	0.226
Day 42			16.8607	10.9154	16.5183	16.4782										
Day 77			20.6574	20.6154	20.3304	19.7298										
Day 105			19.2587	21.4561	22.467	20.7427										
Isovalerate, mM																
Overall	ANTE 1	.	4.3695	4.0923	4.0865	4.2529	0.5888	585.7	596.1	.	0.795	<.0001	0.9166	0.739	0.3517	0.925
Day 42			3.5557	3.1038	3.4588	3.8147										
Day 77			4.4827	4.0832	4.0767	4.3873										
Day 105			5.07	5.09	4.724	4.5568										
Overall	ANTE 1	D0	4.3696	4.1036	4.1039	4.2242	0.5935	587.3	597.7	0.217	0.833	<.0001	0.9223	0.685	0.4213	0.891
Day 42			3.5549	3.1162	3.4757	3.7807										
Day 77			4.4857	4.0922	4.0944	4.3543										
Day 105			5.0683	5.1024	4.7417	4.5376										
Overall	SPPOW	.	4.0406	4.1011	4.0895	4.2505	0.3737	563.1	567.2	.	0.886	1E-04	0.4514	0.482	0.7963	0.777
Day 42			3.5391	3.121	3.4678	3.8041										
Day 77			4.4957	4.0922	4.0767	4.3873										
Day 105			4.0868	5.09	4.724	4.56										

Overall	SPPOW	D0	4.0363	4.1131	4.1075	4.2234	0.3736	564.8	569	0.195	0.921	1E-04	0.4492	0.517	0.9187	0.809
Day 42			3.5397	3.1344	3.4853	3.7726										
Day 77			4.4985	4.1015	4.095	4.3571										
Day 105			4.0706	5.1033	4.7423	4.5404										
Valerate, mM																
Overall	ANTE 1	.	3.2263	3.4423	3.3022	3.2412	0.5237	590.5	600.9	.	0.956	0.547	0.0824	0.943	0.6436	0.747
Day 42			2.7407	2.6363	3.3445	3.7241										
Day 77			3.4773	3.9677	2.9707	3.0973										
Day 105			3.4609	3.7229	3.5913	2.902										
Overall	ANTE 1	D0	3.2066	3.4532	3.3259	3.2149	0.5091	590.8	601.1	0.045	0.926	0.555	0.0845	0.937	0.5398	0.766
Day 42			2.7348	2.6519	3.364	3.7007										
Day 77			3.4715	3.9726	3.0008	3.0695										
Day 105			3.4135	3.7351	3.613	2.8746										
Overall	SPPOW	.	3.2264	3.4451	3.3	3.0683	0.4127	570.4	574.5	.	0.828	0.159	0.1115	0.626	0.4309	0.829
Day 42			2.7407	2.6469	3.3373	3.2059										
Day 77			3.4773	3.9656	2.9715	3.0973										
Day 105			3.4613	3.7229	3.5913	2.9018										
Overall	SPPOW	D0	3.2214	3.4502	3.3216	3.0401	0.4062	567.8	571.9	0.032	0.767	0.157	0.1107	0.587	0.3603	0.87
Day 42			2.7307	2.653	3.3572	3.1857										
Day 77			3.4673	3.9663	2.9981	3.0648										
Day 105			3.4661	3.7314	3.6095	2.8697										
Caproate, mM																
Overall	ANTE 1	.	0.4513	0.541	0.4018	0.385	0.089	24.4	34.8	.	0.029	2E-04	0.2046	0.05	0.1683	0.046
Day 42			0.428	0.5529	0.4184	0.4928										
Day 77			0.5673	0.711	0.414	0.4007										
Day 105			0.3587	0.3593	0.373	0.2614										
Overall	ANTE 1	D0	0.4552	0.5261	0.4173	0.3796	0.0907	24.5	34.9	0.038	0.073	2E-04	0.1991	0.056	0.1671	0.172
Day 42			0.4319	0.5369	0.4346	0.4865										
Day 77			0.5712	0.6961	0.4281	0.3931										

Day 105			0.3625	0.3454	0.3893	0.2593										
Overall	SPPOW	.	0.4513	0.5421	0.4006	0.3854	0.0689	44.1	48.3	.	0.016	7E-04	0.2133	0.04	0.1519	0.032
Day 42			0.428	0.5546	0.415	0.4923										
Day 77			0.5673	0.7123	0.414	0.4007										
Day 105			0.3587	0.3593	0.3729	0.2631										
Overall	SPPOW	D0	0.4533	0.5343	0.4085	0.3825	0.0695	47.5	51.6	0.33	0.03	8E-04	0.2161	0.039	0.1463	0.079
Day 42			0.43	0.5465	0.4229	0.489										
Day 77			0.5693	0.7044	0.4213	0.3967										
Day 105			0.3607	0.3521	0.3813	0.2617										
Acetate, molar %																
Overall	ANTE 1	.	57.0498	57.0737	56.0406	56.2390	1.5363	977.4	987.8	.	0.8473	<.0001	0.7782	0.4569	0.9334	0.6262
Day 42			59.6087	60.5755	57.9337	58.4653										
Day 77			55.2187	54.3629	54.7813	53.8627										
Day 105			56.3220	56.2829	55.4067	56.3889										
Overall	ANTE 1	D0	56.8214	57.1873	56.0745	56.3303	1.3945	969.3	979.7	0.001	0.848	<.0001	0.7848	0.546	0.9542	0.51
Day 42			59.3803	60.6832	57.9919	58.4893										
Day 77			54.9903	54.4793	54.8031	53.9813										
Day 105			56.0936	56.3993	55.4285	56.5201										
Overall	SPPOW	.	57.0498	57.0734	56.0521	56.2223	1.4071	973.4	977.5	.	0.851	<.0001	0.7824	0.456	0.9446	0.637
Day 42			59.6087	60.5744	57.9684	58.4154										
Day 77			55.2187	54.3629	54.7813	53.8627										
Day 105			56.322	56.2829	55.4067	56.3887										
Overall	SPPOW	D0	56.8148	57.1908	56.0714	56.3395	1.3298	964.3	968.5	6E-04	0.85	<.0001	0.7772	0.554	0.9554	0.507
Day 42			59.3737	60.6869	57.9814	58.5088										
Day 77			54.9837	54.4827	54.8038	53.9848										
Day 105			56.087	56.4027	55.4291	56.5248										
Propionate, molar %																
Overall	ANTE 1	.	26.4504	27.3708	28.4577	28.4222	2.1929	1074.1	1084.5	.	0.7361	0.0003	0.9946	0.2944	0.7491	0.8478
Day 42			24.2920	25.1958	26.7990	26.8005										

Day 77			27.9727	29.3407	29.5813	30.3273										
Day 105			27.0867	27.5757	28.9927	28.1387										
Overall	ANTE 1	D0	27.3802	27.2031	28.3304	28.0051	2.0078	1056	1067	<.0001	0.908	6E-04	0.9749	0.59	0.9523	0.62
Day 42			25.2217	25.0624	27.1657	26.414										
Day 77			28.9024	29.156	29.2071	29.9612										
Day 105			28.0164	27.391	28.6184	27.6402										
Overall	SPPOW	.	26.4504	27.3659	28.4274	28.449	1.9805	1075	1079	.	0.734	0.002	0.9949	0.289	0.7641	0.86
Day 42			24.292	25.1814	26.7082	26.8827										
Day 77			27.9727	29.3407	29.5813	30.3273										
Day 105			27.0867	27.5757	28.9927	28.1371										
Overall	SPPOW	D0	27.3558	27.2226	28.0143	28.0414	1.7195	1049	1053	<.0001	0.941	0.002	0.9943	0.592	0.9461	0.751
Day 42			25.1974	25.0787	26.1596	26.4762										
Day 77			28.878	29.1771	29.2359	29.9897										
Day 105			27.992	27.4121	28.6472	27.6583										
Isobutyrate, molar %																
Overall	ANTE 1	.	1.1367	1.0695	1.0821	1.1551	0.08836	115.2	125.6	.	0.5915	<.0001	0.7681	0.7683	0.1778	0.9329
Day 42			1.0940	0.9227	0.9170	0.9957										
Day 77			1.2720	1.1900	1.2533	1.3487										
Day 105			1.0440	1.0957	1.0760	1.1208										
Overall	ANTE 1	D0	1.1415	1.075	1.0767	1.1501	0.0899	118	128.4	0.494	0.606	<.0001	0.7728	0.909	0.1793	0.988
Day 42			1.0989	0.9294	0.9102	0.9911										
Day 77			1.2769	1.1949	1.2485	1.3427										
Day 105			1.0489	1.1006	1.0712	1.1164										
Overall	SPPOW	.	1.1367	1.0701	1.0811	1.1562	0.0854	109.7	113.8	.	0.573	<.0001	0.7628	0.759	0.1678	0.954
Day 42			1.094	0.9246	0.9139	0.9983										
Day 77			1.272	1.19	1.2533	1.3487										
Day 105			1.044	1.0957	1.076	1.1218										
Overall	SPPOW	D0	1.141	1.0749	1.0764	1.1516	0.086	112.6	116.7	0.521	0.587	<.0001	0.7652	0.888	0.1695	0.978
Day 42			1.0984	0.9303	0.9084	0.9937										

Day 77			1.2764	1.1944	1.249	1.3433										
Day 105			1.0484	1.1001	1.0717	1.1178										
Butyrate, molar %																
Overall	ANTE 1	.	10.8878	9.7588	9.8909	9.9048	1.0107	844.2	854.5	.	0.6217	0.1036	0.9766	0.3593	0.4074	0.6556
Day 42			10.7673	8.7444	9.2208	9.1076										
Day 77			11.0480	10.0771	10.1227	10.2107										
Day 105			10.8480	10.4550	10.3293	10.3963										
Overall	ANTE 1	D0	10.2776	9.6761	10.2139	10.3051	0.9304	831.1	841.5	<.0001	0.871	0.099	0.9709	0.826	0.5691	0.56
Day 42			10.1571	8.6434	9.5502	9.5474										
Day 77			10.4378	10.0036	10.4425	10.5559										
Day 105			10.2378	10.3814	10.6491	10.812										
Overall	SPPOW	.	10.8878	9.6161	9.8898	9.9067	0.949	835.8	840	.	0.559	0.078	0.9334	0.377	0.3437	0.555
Day 42			10.7673	8.3161	9.2174	9.1154										
Day 77			11.048	10.0771	10.1227	10.2107										
Day 105			10.848	10.455	10.3293	10.3939										
Overall	SPPOW	D0	10.2411	9.6745	10.2343	10.3346	0.8636	828.8	833	<.0001	0.87	0.124	0.9722	0.767	0.5866	0.564
Day 42			10.1207	8.6472	9.573	9.6259										
Day 77			10.4014	9.9992	10.4616	10.5766										
Day 105			10.2014	10.3771	10.6682	10.8014										
Isovalerate, molar %																
Overall	ANTE 1	.	2.4203	2.2610	2.2623	2.3397	0.2827	371.8	382.2	.	0.7456	0.2953	0.9412	0.6558	0.3262	0.8748
Day 42			2.2482	2.1770	2.2094	2.2653										
Day 77			2.3260	2.1009	2.2533	2.3860										
Day 105			2.6867	2.5050	2.3240	2.3679										
Overall	ANTE 1	D0	2.5183	2.335	2.2547	2.3154	0.283	407.7	418.1	0.248	0.451	0.373	0.9974	0.224	0.3211	0.945
Day 42			2.3656	2.1943	2.1998	2.2345										
Day 77			2.4856	2.2907	2.2468	2.3586										
Day 105			2.7036	2.52	2.3175	2.353										
Overall	SPPOW	.	2.2615	2.2614	2.26	2.341	0.1837	343.2	347.4	.	0.941	0.591	0.83	0.633	0.7141	0.865

Day 42			2.2517	2.1796	2.2028	2.2699										
Day 77			2.3216	2.0997	2.2533	2.386										
Day 105			2.2112	2.505	2.324	2.3672										
Overall	SPPOW	D0	2.284	2.2826	2.2517	2.3076	0.1839	343.5	347.7	0.1	0.986	0.58	0.8301	0.936	0.7906	0.808
Day 42			2.2724	2.2033	2.1924	2.2306										
Day 77			2.3504	2.1189	2.246	2.3513										
Day 105			2.2293	2.5258	2.3167	2.3407										
Valerate, molar %																
Overall	ANTE 1	.	1.7403	1.8800	1.7266	1.7097	0.2146	298.5	308.9	.	0.7417	0.1901	0.1685	0.6424	0.5110	0.4245
Day 42			1.6200	1.9684	1.9546	1.9975										
Day 77			1.7360	1.9622	1.5886	1.6540										
Day 105			1.8648	1.7093	1.6367	1.4776										
Overall	ANTE 1	D0	1.6886	1.833	1.7245	1.6906	0.2117	375.8	386.2	0.153	0.759	0.057	0.4421	0.83	0.4044	0.497
Day 42			1.6334	1.9742	1.952	1.9679										
Day 77			1.7494	1.8153	1.5876	1.6396										
Day 105			1.683	1.7094	1.634	1.4644										
Overall	SPPOW	.	1.6868	1.8409	1.7303	1.6388	0.1477	242.7	246.9	.	0.594	0.087	0.3819	0.59	0.2512	0.554
Day 42			1.62	1.9731	1.9542	1.7856										
Day 77			1.736	1.8278	1.6	1.654										
Day 105			1.7045	1.722	1.6367	1.4768										
Overall	SPPOW	D0	1.7013	1.8401	1.7262	1.6229	0.1471	242.9	247	0.154	0.553	0.087	0.3845	0.461	0.2527	0.579
Day 42			1.6337	1.9719	1.9492	1.7716										
Day 77			1.7497	1.8275	1.597	1.6367										
Day 105			1.7206	1.7209	1.6324	1.4604										
Caproate, molar %																
Overall	ANTE 1	.	0.2456	0.3032	0.2122	0.2130	0.03852	-217.2	-206.8	.	0.0048	<.0001	0.1016	0.0296	0.1419	0.0072
Day 42			0.2687	0.3892	0.2551	0.2884										
Day 77			0.2827	0.3570	0.2107	0.2133										
Day 105			0.1853	0.1635	0.1708	0.1371										

Overall	ANTE 1	D0	0.2459	0.3026	0.213	0.2125	0.0387	-90.9	-80.6	0.809	0.006	<.0001	0.1022	0.03	0.1421	0.011
Day 42			0.269	0.3885	0.2559	0.2879										
Day 77			0.283	0.3564	0.2114	0.2127										
Day 105			0.1857	0.1628	0.1717	0.1369										
Overall	SPPOW	.	0.2456	0.3132	0.2122	0.2141	0.0341	-179.4	-175.2	.	0.003	<.0001	0.3192	0.034	0.1098	0.004
Day 42			0.2687	0.3896	0.2533	0.2881										
Day 77			0.2827	0.3556	0.2107	0.2133										
Day 105			0.1853	0.1943	0.1726	0.1408										
Overall	SPPOW	D0	0.245	0.3143	0.2109	0.215	0.0345	-176	-171.8	0.783	0.003	<.0001	0.3214	0.037	0.1147	0.005
Day 42			0.2681	0.3908	0.2521	0.289										
Day 77			0.2821	0.3569	0.2095	0.2144										
Day 105			0.1848	0.1954	0.1712	0.1415										
Acetate:Propionate, mol/mol																
Overall	ANTE 1	.	2.3858	2.2957	2.1675	2.1815	0.262	399.9	410.3	.	0.798	<.0001	0.9141	0.356	0.772	0.823
Day 42			2.6685	2.6207	2.3191	2.4379										
Day 77			2.0761	2.0771	2.018	1.8902										
Day 105			2.4129	2.1894	2.1653	2.2166										
Overall	ANTE 1	D0	2.3175	2.2714	2.2382	2.2062	0.2482	380.3	390.7	<.0001	0.957	<.0001	0.9446	0.581	0.962	0.986
Day 42			2.6002	2.5957	2.4126	2.4489										
Day 77			2.0078	2.0531	2.0774	1.9151										
Day 105			2.3446	2.1653	2.2247	2.2547										
Overall	SPPOW	.	2.3858	2.2986	2.178	2.1721	0.2419	407.9	412.1	.	0.809	2E-04	0.9607	0.353	0.825	0.858
Day 42			2.6685	2.6294	2.3505	2.4095										
Day 77			2.0761	2.0771	2.018	1.8902										
Day 105			2.4129	2.1894	2.1653	2.2166										
Overall	SPPOW	D0	2.3153	2.27	2.2673	2.2032	0.2106	380.7	384.8	<.0001	0.96	1E-04	0.9678	0.606	0.9491	0.875
Day 42			2.5979	2.5949	2.4269	2.4399										
Day 77			2.0055	2.0514	2.077	1.9141										

Day 105			2.3423	2.1637	2.298	2.2557										
Total VFA, mM																
Overall	ANTE 1	.	186.755	183.109	191.502	186.214	17.412	1761	1772	.	0.934	0.002	0.5481	0.869	0.9291	0.535
Day 42			167.447	143.85	166.915	174.159										
Day 77			200.263	202.121	188.713	187.781										
Day 105			192.555	203.356	218.877	196.702										
Overall	ANTE 1	D0	184.459	182.7	193.512	187.007	17.149	1761	1771	0.086	0.846	0.002	0.542	0.654	0.7949	0.464
Day 42			165.151	143.368	169.06	175.11										
Day 77			197.968	201.748	190.655	188.531										
Day 105			190.259	202.983	220.82	197.379										
Overall	SPPOW	.	186.755	183.086	185.805	186.194	14.659	1735	1739	.	0.992	<.0001	0.4065	0.979	0.819	0.827
Day 42			167.447	143.78	149.826	174.15										
Day 77			200.263	202.121	188.713	187.781										
Day 105			192.555	203.356	218.877	196.652										
Overall	SPPOW	D0	183.581	182.581	188.433	187.461	14.388	1731	1735	0.01	0.954	<.0001	0.3732	0.65	0.9987	0.722
Day 42			164.273	143.041	151.77	175.648										
Day 77			197.09	201.734	191.683	189.022										
Day 105			189.381	202.969	221.847	197.714										

Appendix Table 5. Effects of covariance structure and baseline adjustment on nitrogen excretion estimates calculated from formulated diet values on collection days in finishing heifers

			DynOmik, g/d							*P*-value						
Variable	SAS	Cov	0	2.5	5	7.5	SEM	AIC	BIC	Cov	Trt	Day	Trt x Day	Linear	Quadratic	Cubic
Corrected urine N concentration, %																
Overall	ANTE 1	.	0.28	0.307	0.376	0.354	0.107	34.3	44.9	.	0.55	<0.001	0.77	0.22	0.64	0.56
Day 0		.	0.341	0.309	0.276	0.445										
Day 42		.	0.159	0.135	0.267	0.232										
Day 77		.	0.287	0.355	0.483	0.26										
Day 105		.	0.333	0.429	0.479	0.477										
Overall	ANTE 1	D0	0.302	0.292	0.467	0.286	0.124	50.4	57.3	0.014	0.122	0.093	0.94	0.66	0.18	0.054
Day 42		D0	0.273	0.145	0.393	0.216										
Day 77		D0	0.279	0.329	0.506	0.238										
Day 105		D0	0.354	0.403	0.502	0.404										
Overall	SPPOW	.	0.31	0.307	0.404	0.355	0.111	57.4	60.4	.	0.57	0.101	0.62	0.36	0.68	0.32
Day 0		.	0.341	0.308	0.276	0.449										
Day 42		.	0.28	0.135	0.376	0.232										
Day 77		.	0.288	0.355	0.483	0.26										
Day 105		.	0.333	0.429	0.479	0.477										
Overall	SPPOW	D0	0.302	0.291	0.466	0.289	0.112	45.5	48.2	0.008	0.07	0.114	0.95	0.6	0.144	0.032
Day 42		D0	0.274	0.144	0.392	0.218										
Day 77		D0	0.28	0.328	0.504	0.24										
Day 105		D0	0.354	0.402	0.501	0.407										
Urine volume, L/d																
Overall	ANTE 1	.	42	44.47	37.1	31.7	15.398	1029.4	1040.1	.	0.32	0.15	0.65	0.11	0.45	0.61
Day 0		.	36.99	36.39	27.34	18.26										
Day 42		.	50.22	49.28	32.06	40.49										

Day 77		.	41.05	32.34	54.86	32.32										
Day 105		.	39.74	59.85	34.13	35.73										
Overall	ANTE 1	D0	41.37	43.67	40.02	38.75	14.728	695.6	702.5	0.058	0.95	0.92	0.38	0.7	0.77	0.75
Day 42		D0	48.57	49.42	29.18	42.41										
Day 77		D0	39.6	34	55.81	29.24										
Day 105		D0	35.94	47.58	35.08	44.6										
Overall	SPPOW	.	40.98	44.56	36.19	31.66	11.809	1050.5	1053.6	.	0.31	0.31	0.59	0.117	0.43	0.49
Day 0		.	36.99	36.78	27.34	17.92										
Day 42		.	45.6	49.28	28.45	40.69										
Day 77		.	41.04	32.33	54.86	32.32										
Day 105		.	40.29	59.85	34.13	35.73										
Overall	SPPOW	D0	39.64	43.39	40.16	39.18	11.917	706.3	709.1	0.024	0.95	0.98	0.51	0.87	0.68	0.72
Day 42		D0	43.85	49.14	29.43	42.84										
Day 77		D0	39.29	33.73	55.89	29.67										
Day 105		D0	35.79	47.3	35.16	45.03										
Creatinine excretion, g/d																
Overall	ANTE 1	.	17.31	17.06	16.29	16.27	0.441	241.3	252	.	0.115	<0.001	0.24	0.023	0.75	0.44
Day 0		.	14.8	14.43	14.16	14.1										
Day 42		.	17.13	16.98	16.06	16.21										
Day 77		.	18.04	17.76	17	16.86										
Day 105		.	19.26	19.06	17.93	17.88										
Overall	ANTE 1	D0	17.78	17.87	17.15	17.19	0.259	143	150.5	<0.001	0.046	<0.001	0.28	0.019	0.9	0.113
Day 42		D0	16.77	16.92	16.22	16.41										
Day 77		D0	17.67	17.7	17.16	17.07										
Day 105		D0	18.9	19	18.09	18.09										
Overall	SPPOW	.	17.31	17.06	16.29	16.27	0.408	243.1	246.2	.	0.13	<0.001	0.24	0.027	0.76	0.46
Day 0		.	14.8	14.43	14.16	14.1										
Day 42		.	17.14	16.98	16.06	16.21										

Day 77		.	18.04	17.76	17	16.86										
Day 105		.	19.26	19.06	17.93	17.88										
Overall	SPPOW	D0	17.76	17.87	17.16	17.2	0.238	141.2	144.2	<0.001	0.05	<0.001	0.37	0.022	0.87	0.109
Day 42		D0	16.75	16.91	16.23	16.43										
Day 77		D0	17.65	17.7	17.17	17.08										
Day 105		D0	18.88	19	18.1	18.1										
Urinary N, g/d																
Overall	ANTE 1	.	84.5	71.7	128.2	77.7	57.41	1096	1106.7	.	0.05	<0.001	0.17	0.59	0.22	0.014
Day 0		.	60.4	55.8	51	53.7										
Day 42		.	52.7	53.5	58.9	76.2										
Day 77		.	112.4	82	275.5	66.7										
Day 105		.	112.6	95.4	127.2	114.4										
Overall	ANTE 1	D0	92.5	76.6	129.1	85.4	49.069	782.7	789.5	0.56	0.2	0.001	0.53	0.7	0.44	0.049
Day 42		D0	52.2	51.6	65.9	81.7										
Day 77		D0	111.4	81.6	192.8	53.7										
Day 105		D0	113.9	96.5	128.5	120.7										
Overall	SPPOW	.	78.5	74.5	69.7	72.8	18.87	1011.6	1014.7	.	0.85	<0.001	0.32	0.49	0.62	0.79
Day 0		.	60.4	65.4	51	53.7										
Day 42		.	57.6	53.5	64.9	76.7										
Day 77		.	81.4	82	35.9	66.7										
Day 105		.	114.5	97	127.2	94.3										
Overall	SPPOW	D0	81.7	75.8	79.1	86.9	23.475	706.7	709.5	0.122	0.9	<0.001	0.42	0.69	0.52	0.92
Day 42		D0	55.3	49.6	67.8	83.3										
Day 77		D0	77.8	79.7	38.6	55.3										
Day 105		D0	111.9	98	131	122.3										
Fecal N, %																
Overall	ANTE 1	.	2.446	2.472	2.389	2.384	0.159	158.2	168.9	.	0.79	0.27	0.97	0.42	0.83	0.58
Day 0		.	2.509	2.622	2.574	2.408										

Day 42		.	2.395	2.367	2.203	2.411										
Day 77		.	2.406	2.549	2.427	2.456										
Day 105		.	2.474	2.352	2.354	2.26										
Overall	ANTE 1	D0	2.428	2.41	2.325	2.387	0.16	118.7	126	0.41	0.84	0.52	0.94	0.59	0.65	0.58
Day 42		D0	2.393	2.356	2.204	2.422										
Day 77		D0	2.416	2.534	2.421	2.467										
Day 105		D0	2.474	2.341	2.349	2.271										
Overall	SPPOW	.	2.448	2.474	2.389	2.384	0.154	148.7	151.8	.	0.76	0.26	0.97	0.38	0.83	0.55
Day 0		.	2.509	2.622	2.574	2.408										
Day 42		.	2.4	2.373	2.203	2.411										
Day 77		.	2.411	2.549	2.427	2.456										
Day 105		.	2.474	2.352	2.354	2.26										
Overall	SPPOW	D0	2.43	2.413	2.326	2.387	0.156	113.1	116	0.36	0.82	0.53	0.95	0.55	0.64	0.55
Day 42		D0	2.395	2.362	2.208	2.422										
Day 77		D0	2.421	2.534	2.421	2.467										
Day 105		D0	2.474	2.341	2.349	2.271										
Diet N, %																
Overall	ANTE 1	.	1.918	1.915	1.919	1.919	0.007	-581.9	-571.2	.	0.82	<0.001	0.88	0.71	0.66	0.46
Day 0		.	1.918	1.908	1.917	1.917										
Day 42		.	1.875	1.877	1.875	1.879										
Day 77		.	1.97	1.966	1.974	1.963										
Day 105		.	1.91	1.911	1.91	1.916										
Overall	ANTE 1	D0	1.919	1.917	1.92	1.92	0.007	-437.6	-430.1	0.11	0.92	<0.001	0.77	0.74	0.78	0.6
Day 42		D0	1.875	1.875	1.875	1.879										
Day 77		D0	1.971	1.964	1.974	1.963										
Day 105		D0	1.911	1.91	1.91	1.916										
Overall	SPPOW	.	1.918	1.915	1.919	1.919	0.006	-578.5	-575.4	.	0.83	<0.001	0.87	0.7	0.67	0.47
Day 0		.	1.918	1.908	1.917	1.917										

Day 42		.	1.875	1.877	1.875	1.879										
Day 77		.	1.97	1.966	1.974	1.963										
Day 105		.	1.91	1.911	1.91	1.916										
Overall	SPPOW	D0	1.919	1.917	1.92	1.92	0.006	-432.7	-429.7	0.28	0.94	<0.001	0.7	0.73	0.83	0.65
Day 42		D0	1.875	1.876	1.875	1.879										
Day 77		D0	1.97	1.965	1.974	1.963										
Day 105		D0	1.91	1.91	1.91	1.916										
Nitrogen intake, kg/d																
Overall	ANTE 1	.	0.223	0.253	0.202	0.208	0.022	-368.3	-357.6	.	<0.001	0.007	0.2	0.015	0.16	<0.001
Day 0		.	0.203	0.215	0.195	0.198										
Day 42		.	0.212	0.251	0.21	0.215										
Day 77		.	0.23	0.266	0.195	0.22										
Day 105		.	0.248	0.282	0.209	0.197										
Overall	ANTE 1	D0	0.23	0.265	0.205	0.211	0.024	-261	-253.5	0.53	0.003	0.35	0.25	0.023	0.2	0.003
Day 42		D0	0.212	0.249	0.21	0.216										
Day 77		D0	0.231	0.264	0.195	0.221										
Day 105		D0	0.248	0.283	0.21	0.197										
Overall	SPPOW	.	0.225	0.254	0.204	0.202	0.017	-357	-353.9	.	<0.001	0.012	0.32	0.001	0.051	<0.001
Day 0		.	0.203	0.215	0.195	0.198										
Day 42		.	0.212	0.251	0.21	0.215										
Day 77		.	0.238	0.265	0.204	0.199										
Day 105		.	0.248	0.287	0.209	0.197										
Overall	SPPOW	D0	0.233	0.266	0.211	0.211	0.018	-246.7	-243.7	0.31	0.001	0.42	0.49	0.011	0.129	0.004
Day 42		D0	0.212	0.248	0.211	0.216										
Day 77		D0	0.239	0.263	0.211	0.221										
Day 105		D0	0.248	0.286	0.21	0.197										
Nitrogen intake, g/d																

Overall	ANTE 1	.	223.3	253.3	202.4	207.6	21.698	1192.8	1203.5	.	<0.001	0.007	0.2	0.015	0.16	<0.001
Day 0		.	202.8	214.8	195.3	198										
Day 42		.	212.1	250.7	209.6	215.4										
Day 77		.	230.2	265.8	195.4	220.4										
Day 105		.	248	281.7	209.2	196.7										
Overall	ANTE 1	D0	230.4	265.4	205.2	211.3	23.624	899.5	907	0.53	0.003	0.35	0.25	0.023	0.2	0.003
Day 42		D0	212.4	249.4	210.3	215.8										
Day 77		D0	230.5	264.2	195.4	220.9										
Day 105		D0	248.3	282.7	209.9	197.1										
Overall	SPPOW	.	225.4	254.4	204.5	202.3	17.289	1121.3	1124.3	.	<0.001	0.012	0.32	0.001	0.051	<0.001
Day 0		.	202.8	214.8	195.3	198										
Day 42		.	212.5	250.7	209.6	215.4										
Day 77		.	238	265.3	203.8	199.3										
Day 105		.	248	286.9	209.2	196.7										
Overall	SPPOW	D0	233.3	265.9	210.7	211.4	18.253	872.4	875.4	0.31	0.001	0.42	0.49	0.011	0.129	0.004
Day 42		D0	212.5	248.2	210.7	216										
Day 77		D0	239.2	262.8	211.1	221.1										
Day 105		D0	248.4	286.5	210.2	197.3										
Rumen fluid pH																
Overall	ANTE 1	.	6.79	6.85	6.71	6.86	0.106	197.7	212.4	.	0.23	<0.001	0.06	0.76	0.48	0.058
Day 0		.	6.98	6.99	7.07	6.99										
Day 42		.	6.72	6.88	6.51	6.73										
Day 77		.	6.79	6.74	6.77	6.93										
Day 105		.	6.66	6.81	6.49	6.78										
Overall	ANTE 1	D0	6.71	6.83	6.57	6.85	0.152	94.3	101.6	0.4	0.126	0.087	0.65	0.66	0.36	0.035
Day 42		D0	6.73	6.81	6.39	6.76										
Day 77		D0	6.77	6.82	6.8	7.01										
Day 105		D0	6.62	6.86	6.51	6.77										

	Overall	SPPOW	.	6.75	6.81	6.72	6.88	0.141	110.8	115	.	0.35	0.002	0.27	0.34	0.49	0.19
	Day 0		.	6.89	6.83	7.1	6.96										
	Day 42		.	6.72	6.78	6.42	6.76										
	Day 77		.	6.77	6.8	6.82	7.01										
	Day 105		.	6.61	6.84	6.53	6.77										
	Overall	SPPOW	D0	6.71	6.83	6.56	6.85	0.148	89.9	92.8	0.16	0.072	0.071	0.67	0.67	0.31	0.018
	Day 42		D0	6.73	6.81	6.39	6.76										
	Day 77		D0	6.78	6.83	6.79	7.01										
	Day 105		D0	6.62	6.86	6.5	6.77										
Rumen ammonia concentration, mM																	
	Overall	ANTE 1	.	4.497	4.485	4.595	4.609	0.608	901.2	915.9	.	0.99	0.088	0.117	0.74	0.96	0.87
	Day 0		.	3.929	3.75	4.688	4.388										
	Day 42		.	4.632	4.363	4.098	4.445										
	Day 77		.	4.756	3.815	4.58	4.988										
	Day 105		.	4.672	6.011	5.013	4.614										
	Overall	ANTE 1	D0	4.944	5.176	4.245	5.234	0.805	357.6	365	0.32	0.53	0.37	0.117	0.98	0.47	0.2
	Day 42		D0	4.33	5.203	3.598	5.228										
	Day 77		D0	5.768	4.088	4.11	5.482										
	Day 105		D0	4.734	6.237	5.026	4.991										
	Overall	SPPOW	.	4.526	4.893	4.643	4.926	0.803	485.5	489.7	.	0.87	0.099	0.31	0.6	0.92	0.54
	Day 0		.	3.517	4.049	4.524	4.018										
	Day 42		.	4.236	5.21	4.725	5.224										
	Day 77		.	5.69	4.089	4.203	5.477										
	Day 105		.	4.66	6.222	5.119	4.987										
	Overall	SPPOW	D0	4.986	5.188	4.538	5.24	0.868	372	375	0.145	0.77	0.65	0.22	0.96	0.64	0.36
	Day 42		D0	4.373	5.218	4.565	5.234										
	Day 77		D0	5.81	4.097	4.066	5.488										

Day 105		D0	4.776	6.249	4.982	4.997									
Rumen ammonia concentration, mg/dL															
Overall	ANTE 1	.	6.3	6.283	6.437	6.457	0.851	1044.9	1059.5	.	0.99	0.088	0.117	0.74	0.96	0.87
Day 0		.	5.504	5.254	6.568	6.147									
Day 42		.	6.489	6.113	5.741	6.227									
Day 77		.	6.663	5.344	6.416	6.988									
Day 105		.	6.545	8.422	7.022	6.464									
Overall	ANTE 1	D0	6.927	7.252	5.947	7.332	1.128	410.9	418.2	0.32	0.53	0.37	0.117	0.98	0.47	0.2
Day 42		D0	6.067	7.289	5.041	7.324									
Day 77		D0	8.08	5.728	5.759	7.68									
Day 105		D0	6.633	8.738	7.042	6.992									
Overall	SPPOW	.	6.34	6.854	6.504	6.902	1.125	558.3	562.5	.	0.87	0.099	0.31	0.6	0.92	0.54
Day 0		.	4.928	5.673	6.338	5.629									
Day 42		.	5.934	7.299	6.62	7.319									
Day 77		.	7.972	5.729	5.888	7.674									
Day 105		.	6.528	8.717	7.171	6.986									
Overall	SPPOW	D0	6.986	7.269	6.357	7.341	1.216	426	428.9	0.145	0.77	0.65	0.22	0.96	0.64	0.36
Day 42		D0	6.126	7.311	6.396	7.333									
Day 77		D0	8.139	5.74	5.696	7.688									
Day 105		D0	6.692	8.755	6.98	7.001									
Creatinine, mg/dL															
Overall	ANTE 1	.	68.9	67.1	73.9	84	28.56	1166	1176.7	.	0.7	0.018	0.45	0.29	0.58	0.91
Day 0		.	83.5	80	76.7	126.4									
Day 42		.	45.2	40.1	82.1	49.8									
Day 77		.	73.4	85	60.7	72.9									
Day 105		.	73.7	63.3	76.1	86.8									
Overall	ANTE 1	D0	65.89	65.09	74.33	68.68	24.197	768.5	775.3	0.15	0.93	0.099	0.57	0.74	0.83	0.61

Day 42		D0	45.65	40.91	83.59	48.32										
Day 77		D0	73.42	78.49	61.99	81.51										
Day 105		D0	78.6	75.87	77.4	76.23										
Overall	SPPOW	.	73.5	66.9	73.8	84.4	23.202	1190.8	1193.9	.	0.71	0.18	0.74	0.41	0.42	0.84
Day 0		.	83.5	80	76.7	128.3										
Day 42		.	65.2	40.1	81.5	49.7										
Day 77		.	73.5	84.3	60.7	72.9										
Day 105		.	71.6	63.3	76.1	86.8										
Overall	SPPOW	D0	73.44	65.68	75.56	66.65	21.626	788.7	791.4	0.002	0.61	0.42	0.85	0.73	0.92	0.19
Day 42		D0	65.6	41.5	85.75	46.28										
Day 77		D0	73.6	79.08	62.76	79.47										
Day 105		D0	81.11	76.46	78.17	74.2										
Fecal iNDF, %																
Overall	ANTE 1	.	19.682	18.212	20.247	20.663	1.805	608.3	618.5	.	0.46	0.003	0.15	0.33	0.41	0.32
Day 0		.	17.583	15.629	18.548	18.361										
Day 42		.	18.191	18.888	19.991	21.969										
Day 77		.	21.458	20.664	20.468	19.771										
Day 105		.	21.497	17.667	21.98	22.551										
Overall	ANTE 1	D0	20.491	20.331	19.814	20.988	1.495	434.9	442.2	0.002	0.87	0.24	0.095	0.83	0.51	0.67
Day 42		D0	18.47	20.245	18.093	21.527										
Day 77		D0	21.503	21.692	19.918	19.328										
Day 105		D0	21.501	19.057	21.431	22.108										
Overall	SPPOW	.	19.756	18.237	20.329	20.663	1.61	604.2	607.1	.	0.39	0.004	0.132	0.31	0.38	0.26
Day 0		.	17.583	15.629	18.548	18.361										
Day 42		.	18.435	19.085	20.32	21.969										
Day 77		.	21.508	20.618	20.468	19.771										
Day 105		.	21.497	17.616	21.98	22.551										
Overall	SPPOW	D0	20.525	20.316	20.381	20.992	1.64	442.7	445.6	0.002	0.97	0.59	0.103	0.76	0.71	0.96

Day 42		D0	18.462	20.272	19.79	21.532										
Day 77		D0	21.598	21.696	19.92	19.333										
Day 105		D0	21.516	18.98	21.433	22.113										
Diet iNDF intake, kg/d																
Overall	ANTE 1	.	0.416	0.471	0.381	0.382	0.031	-216.4	-206.1	.	<0.001	<0.001	0.23	0.006	0.074	0.001
Day 0		.	0.447	0.491	0.442	0.447										
Day 42		.	0.401	0.49	0.41	0.397										
Day 77		.	0.315	0.347	0.252	0.289										
Day 105		.	0.501	0.557	0.422	0.393										
Overall	ANTE 1	D0	0.407	0.461	0.364	0.361	0.031	-153.9	-146.6	0.42	0.002	<0.001	0.18	0.006	0.119	0.007
Day 42		D0	0.402	0.487	0.415	0.398										
Day 77		D0	0.316	0.342	0.254	0.29										
Day 105		D0	0.502	0.553	0.424	0.394										
Overall	SPPOW	.	0.416	0.471	0.382	0.382	0.029	-223.4	-220.5	.	<0.001	<0.001	0.21	0.004	0.062	<0.001
Day 0		.	0.447	0.491	0.442	0.447										
Day 42		.	0.401	0.492	0.41	0.397										
Day 77		.	0.315	0.345	0.252	0.289										
Day 105		.	0.501	0.558	0.422	0.393										
Overall	SPPOW	D0	0.406	0.46	0.363	0.361	0.029	-160.7	-157.7	0.38	<0.001	<0.001	0.17	0.004	0.11	0.004
Day 42		D0	0.402	0.487	0.412	0.398										
Day 77		D0	0.316	0.34	0.254	0.29										
Day 105		D0	0.502	0.553	0.424	0.394										
Pellet iNDF intake, kg/d																
Overall	ANTE 1	.	0.038	0.044	0.039	0.036	0.021	-350	-339.7	.	0.9	<0.001	0.73	0.71	0.58	0.71
Day 0		.	0.019	0.006	0.015	0.011										
Day 42		.	0.008	0.014	0.023	0.023										
Day 77		.	0.069	0.068	0.067	0.047										

Day 105		.	0.058	0.087	0.049	0.061										
Overall	ANTE 1	D0	0.047	0.053	0.047	0.044	0.021	-233.2	-225.9	0.078	0.94	<0.001	0.59	0.75	0.65	0.76
Day 42		D0	0.01	0.011	0.025	0.024										
Day 77		D0	0.071	0.064	0.068	0.047										
Day 105		D0	0.06	0.084	0.049	0.062										
Overall	SPPOW	.	0.043	0.044	0.041	0.04	0.018	-315.4	-312.5	.	0.98	<0.001	0.66	0.73	0.87	0.85
Day 0		.	0.038	0.006	0.026	0.027										
Day 42		.	0.006	0.015	0.021	0.023										
Day 77		.	0.069	0.068	0.067	0.047										
Day 105		.	0.058	0.087	0.049	0.061										
Overall	SPPOW	D0	0.046	0.054	0.046	0.044	0.018	-229.9	-227	0.17	0.92	<0.001	0.7	0.73	0.65	0.67
Day 42		D0	0.009	0.012	0.022	0.023										
Day 77		D0	0.071	0.065	0.067	0.047										
Day 105		D0	0.06	0.084	0.049	0.062										
Total iNDF intake, kg/d																
Overall	ANTE 1	.	0.451	0.516	0.423	0.421	0.037	-180	-169.8	.	0.001	<0.001	0.26	0.024	0.059	0.003
Day 0		.	0.454	0.497	0.464	0.458										
Day 42		.	0.406	0.504	0.431	0.425										
Day 77		.	0.384	0.42	0.323	0.34										
Day 105		.	0.558	0.644	0.474	0.459										
Overall	ANTE 1	D0	0.45	0.524	0.412	0.408	0.038	-126.1	-118.7	0.91	0.004	<0.001	0.2	0.023	0.088	0.007
Day 42		D0	0.406	0.506	0.44	0.425										
Day 77		D0	0.384	0.42	0.323	0.34										
Day 105		D0	0.558	0.645	0.474	0.459										
Overall	SPPOW	.	0.458	0.517	0.424	0.425	0.035	-182.9	-180	.	0.002	<0.001	0.22	0.017	0.105	0.004
Day 0		.	0.485	0.497	0.467	0.474										
Day 42		.	0.406	0.51	0.433	0.425										
Day 77		.	0.384	0.414	0.323	0.34										

Day 105		.	0.558	0.645	0.474	0.459										
Overall	SPPOW	D0	0.45	0.523	0.41	0.408	0.035	-131.2	-128.3	0.96	0.002	<0.001	0.25	0.018	0.09	0.004
Day 42		D0	0.407	0.507	0.433	0.425										
Day 77		D0	0.384	0.416	0.323	0.34										
Day 105		D0	0.558	0.645	0.474	0.459										
Fecal output, kg/d																
Overall	ANTE 1	.	2.41	2.971	2.123	2.135	0.308	239.7	249.9	.	0.006	<0.001	0.45	0.041	0.129	0.007
Day 0		.	2.86	3.326	2.544	2.578										
Day 42		.	2.211	2.703	1.966	2.011										
Day 77		.	1.882	2.182	1.679	1.833										
Day 105		.	2.687	3.675	2.301	2.118										
Overall	ANTE 1	D0	2.244	2.715	2.103	2.043	0.273	163.6	171	0.014	0.047	<0.001	0.2	0.113	0.119	0.044
Day 42		D0	2.187	2.567	2.172	2.067										
Day 77		D0	1.872	2.053	1.757	1.888										
Day 105		D0	2.673	3.523	2.378	2.174										
Overall	SPPOW	.	2.427	2.981	2.25	2.155	0.302	259.7	262.7	.	0.015	<0.001	0.25	0.066	0.086	0.026
Day 0		.	2.909	3.326	2.578	2.657										
Day 42		.	2.226	2.73	2.441	2.011										
Day 77		.	1.887	2.191	1.679	1.833										
Day 105		.	2.687	3.676	2.301	2.118										
Overall	SPPOW	D0	2.241	2.697	2.072	2.051	0.282	166.3	169.3	0.006	0.05	<0.001	0.123	0.115	0.15	0.037
Day 42		D0	2.196	2.559	2.059	2.075										
Day 77		D0	1.858	2.033	1.768	1.896										
Day 105		D0	2.67	3.5	2.39	2.182										
DM digestibility, fraction																
Overall	ANTE 1	.	0.794	0.776	0.801	0.804	0.022	-318.7	-308.4	.	0.25	<0.001	0.23	0.23	0.33	0.18
Day 0		.	0.723	0.707	0.75	0.748										

Day 42		.	0.809	0.807	0.827	0.832										
Day 77		.	0.851	0.843	0.835	0.841										
Day 105		.	0.792	0.748	0.792	0.795										
Overall	ANTE 1	D0	0.819	0.806	0.808	0.816	0.017	-258.8	-251.5	0.003	0.79	<0.001	0.24	0.83	0.33	0.86
Day 42		D0	0.81	0.813	0.808	0.818										
Day 77		D0	0.854	0.849	0.83	0.837										
Day 105		D0	0.794	0.757	0.787	0.792										
Overall	SPPOW	.	0.794	0.777	0.794	0.8	0.019	-323.6	-320.7	.	0.6	<0.001	0.42	0.53	0.36	0.42
Day 0		.	0.724	0.707	0.746	0.742										
Day 42		.	0.807	0.809	0.803	0.822										
Day 77		.	0.852	0.842	0.835	0.841										
Day 105		.	0.792	0.748	0.792	0.795										
Overall	SPPOW	D0	0.82	0.807	0.813	0.816	0.017	-259.2	-256.3	0.007	0.85	<0.001	0.2	0.92	0.46	0.64
Day 42		D0	0.81	0.816	0.822	0.818										
Day 77		D0	0.855	0.849	0.83	0.837										
Day 105		D0	0.794	0.756	0.787	0.792										
Fecal N, g/d																
Overall	ANTE 1	.	58.33	72.87	51.48	50.38	9.629	874.5	884.8	.	<0.001	<0.001	0.34	0.011	0.045	0.002
Day 0		.	70.87	87.89	69.12	62.73										
Day 42		.	51.63	63.32	43.66	47.66										
Day 77		.	45.18	53.22	39.66	43.63										
Day 105		.	65.62	87.05	53.49	47.5										
Overall	ANTE 1	D0	54.21	64.44	47.18	47.78	6.477	630.6	637.9	0.064	0.017	<0.001	0.19	0.034	0.2	0.014
Day 42		D0	51.64	60.94	47.27	49.33										
Day 77		D0	45.18	50.64	39.91	45.07										
Day 105		D0	65.8	81.75	54.35	48.94										
Overall	SPPOW	.	59.27	71.77	53.1	50.7	8.198	879.5	882.4	.	0.008	<0.001	0.73	0.025	0.091	0.021
Day 0		.	71.61	87.89	67.42	63.78										

	Day 42		.	52.17	64.31	54.07	47.89										
	Day 77		.	47.67	53.22	37.43	43.63										
	Day 105		.	65.62	81.66	53.49	47.5										
	Overall	SPPOW	D0	55.34	62.04	48.04	48.16	6.37	603.8	606.8	0.013	0.04	<0.001	0.37	0.029	0.36	0.043
	Day 42		D0	52.16	60.84	45.75	49.71										
	Day 77		D0	48.03	49.64	43.79	45.45										
	Day 105		D0	65.83	75.65	54.56	49.32										
Total N excretion, g/d																	
	Overall	ANTE 1	.	147.9	147.2	159.2	125.2	45.305	965.9	976.2	.	0.37	<0.001	0.7	0.37	0.25	0.36
	Day 0		.	136.5	136.8	122.6	122.5										
	Day 42		.	103.1	128.8	102.8	106.2										
	Day 77		.	167.2	141.7	230.8	110.3										
	Day 105		.	185	181.6	180.7	161.9										
	Overall	ANTE 1	D0	151.4	150.5	173	125.9	51.943	669.1	675.9	0.68	0.45	<0.001	0.55	0.56	0.27	0.32
	Day 42		D0	103	130.7	105.8	112.2										
	Day 77		D0	166.3	140.4	231.3	95.7										
	Day 105		D0	185.1	180.5	181.8	169.7										
	Overall	SPPOW	.	139.9	148.5	121.7	125.3	23.078	965.3	968.2	.	0.16	<0.001	0.54	0.086	0.79	0.128
	Day 0		.	135.1	145.5	118.4	121.7										
	Day 42		.	106.9	127.8	114.2	127.3										
	Day 77		.	133.7	138.7	73.4	110.3										
	Day 105		.	184	181.8	180.7	142										
	Overall	SPPOW	D0	138.8	142.7	124.2	137.5	26.405	635.7	638.4	0.018	0.79	<0.001	0.57	0.69	0.71	0.37
	Day 42		D0	103.9	121.2	108.5	138.3										
	Day 77		D0	129.7	131.5	76.4	100.1										
	Day 105		D0	182.9	175.4	187.9	174.1										
Nitrogen retention, g/d																	

Overall	ANTE 1	.	79.7	107.9	43.6	84.9	47.921	968.3	978.6	.	0.027	<0.001	0.2	0.44	0.65	0.004
Day 0		.	55.5	74.6	74.8	79.9										
Day 42		.	119.4	134.4	111.8	114.6										
Day 77		.	75.7	124.9	-40.4	110.2										
Day 105		.	68.1	97.6	28.4	34.8										
Overall	ANTE 1	D0	90.1	120.6	32	86.7	54.906	674.9	681.8	0.46	0.039	<0.001	0.31	0.3	0.56	0.008
Day 42		D0	121.3	131.4	112.8	117.8										
Day 77		D0	76.9	132.6	-44.1	113.7										
Day 105		D0	72.1	97.8	27.4	28.5										
Overall	SPPOW	.	89.5	105.3	83	80.8	22.469	953.2	956.1	.	0.094	<0.001	0.49	0.126	0.22	0.09
Day 0		.	64.2	66.3	76.9	81.5										
Day 42		.	106.8	133.7	111.3	87.2										
Day 77		.	120.6	123.4	115.2	101.8										
Day 105		.	66.3	97.9	28.4	52.7										
Overall	SPPOW	D0	104.9	120.8	80	71.3	26.059	635.3	638.1	0.019	0.022	<0.001	0.82	0.01	0.3	0.111
Day 42		D0	111.1	138.8	98.3	80.9										
Day 77		D0	128.7	125.2	117.2	109.1										
Day 105		D0	74.8	98.3	24.6	23.9										
Nitrogen digestibility, fraction																
Overall	ANTE 1	.	0.739	0.708	0.749	0.759	0.034	-250	-239.7	.	0.037	<0.001	0.28	0.075	0.108	0.074
Day 0		.	0.64	0.595	0.654	0.688										
Day 42		.	0.76	0.756	0.796	0.782										
Day 77		.	0.817	0.8	0.802	0.803										
Day 105		.	0.737	0.68	0.744	0.762										
Overall	ANTE 1	D0	0.772	0.762	0.772	0.773	0.026	-209.7	-202.4	0.007	0.92	<0.001	0.56	0.78	0.67	0.6
Day 42		D0	0.76	0.771	0.776	0.768										
Day 77		D0	0.818	0.809	0.8	0.797										

Day 105		D0	0.737	0.708	0.741	0.755										
Overall	SPPOW	.	0.739	0.716	0.746	0.756	0.027	-236.1	-233.1	.	0.32	<0.001	0.81	0.24	0.28	0.3
Day 0		.	0.646	0.595	0.66	0.68										
Day 42		.	0.759	0.758	0.762	0.774										
Day 77		.	0.815	0.8	0.817	0.807										
Day 105		.	0.737	0.711	0.744	0.762										
Overall	SPPOW	D0	0.77	0.772	0.774	0.772	0.02	-211.9	-208.9	0.004	1	<0.001	0.83	0.89	0.89	0.94
Day 42		D0	0.759	0.769	0.784	0.766										
Day 77		D0	0.815	0.81	0.796	0.795										
Day 105		D0	0.737	0.737	0.741	0.754										
Nitrogen efficiency, g/g																
Overall	ANTE 1	.	0.34	0.417	0.299	0.393	0.191	20.6	30.8	.	0.49	<0.001	0.64	0.87	0.89	0.133
Day 0		.	0.292	0.344	0.384	0.394										
Day 42		.	0.535	0.505	0.504	0.514										
Day 77		.	0.263	0.457	0.198	0.49										
Day 105		.	0.269	0.361	0.111	0.173										
Overall	ANTE 1	D0	0.362	0.448	0.26	0.398	0.203	45.6	52.5	0.54	0.46	0.001	0.7	0.83	0.75	0.126
Day 42		D0	0.54	0.501	0.483	0.505										
Day 77		D0	0.268	0.475	0.192	0.547										
Day 105		D0	0.279	0.367	0.104	0.142										
Overall	SPPOW	.	0.392	0.409	0.437	0.39	0.085	-30.2	-27.3	.	0.74	<0.001	0.64	0.88	0.34	0.57
Day 0		.	0.318	0.306	0.399	0.4										
Day 42		.	0.49	0.508	0.495	0.403										
Day 77		.	0.488	0.459	0.622	0.497										
Day 105		.	0.272	0.362	0.233	0.26										
Overall	SPPOW	D0	0.45	0.471	0.388	0.328	0.113	14.2	16.9	<0.001	<0.001	<0.001	0.61	<0.001	0.145	0.38
Day 42		D0	0.515	0.557	0.458	0.35										
Day 77		D0	0.526	0.474	0.629	0.519										

Day 105		D0	0.307	0.383	0.076	0.114										
OM intake, kg/d																
Overall	ANTE 1	.	11.25	11.83	10.14	10.07	0.712	1033.9	1048.6	.	<0.001	<0.001	0.2	<0.001	0.32	0.009
Day 0		.	10.36	10.59	9.34	9.29										
Day 42		.	10.7	12.56	11.16	11.24										
Day 77		.	11.74	11.77	10.01	10.46										
Day 105		.	12.21	12.41	10.05	9.29										
Overall	ANTE 1	D0	11.5	12.17	10.47	10.4	0.721	807.3	817.8	0.37	0.014	0.52	0.083	0.012	0.37	0.036
Day 42		D0	10.65	12.48	11.22	11.31										
Day 77		D0	11.69	11.69	10.08	10.53										
Day 105		D0	12.16	12.33	10.12	9.36										
Overall	SPPOW	.	11.25	11.83	10.14	10.07	0.577	1039.6	1043.8	.	<0.001	0.002	0.19	<0.001	0.3	0.007
Day 0		.	10.36	10.59	9.34	9.29										
Day 42		.	10.7	12.56	11.16	11.24										
Day 77		.	11.74	11.77	10.01	10.46										
Day 105		.	12.21	12.41	10.05	9.29										
Overall	SPPOW	D0	11.5	12.17	10.47	10.4	0.628	805.9	810.1	0.4	0.01	0.53	0.118	0.009	0.36	0.03
Day 42		D0	10.65	12.48	11.22	11.31										
Day 77		D0	11.69	11.69	10.07	10.53										
Day 105		D0	12.16	12.34	10.11	9.36										
Fecal OM, kg/d																
Overall	ANTE 1	.	2.062	2.534	1.797	1.795	0.272	222.9	237.6	.	0.009	<0.001	0.58	0.041	0.15	0.011
Day 0		.	2.5	2.865	2.134	2.261										
Day 42		.	1.892	2.266	1.656	1.623										
Day 77		.	1.647	1.905	1.468	1.57										
Day 105		.	2.208	3.098	1.931	1.727										
Overall	ANTE 1	D0	1.886	2.297	1.809	1.669	0.254	152.2	159.5	0.014	0.049	<0.001	0.3	0.102	0.074	0.086
Day 42		D0	1.853	2.141	1.858	1.638										

Day 77		D0	1.622	1.789	1.553	1.607											
Day 105		D0	2.183	2.961	2.015	1.763											
Overall	SPPOW	.	2.079	2.542	1.914	1.828	0.277	241.7	245.9	.	0.027	<0.001	0.28	0.076	0.115	0.04	
Day 0		.	2.553	2.865	2.172	2.338											
Day 42		.	1.906	2.292	2.085	1.675											
Day 77		.	1.647	1.911	1.468	1.57											
Day 105		.	2.208	3.101	1.931	1.727											
Overall	SPPOW	D0	1.885	2.282	1.789	1.704	0.263	155.7	158.6	0.004	0.076	<0.001	0.2	0.141	0.122	0.081	
Day 42		D0	1.866	2.137	1.759	1.723											
Day 77		D0	1.608	1.77	1.573	1.617											
Day 105		D0	2.181	2.939	2.035	1.774											
OM digestibility, fraction																	
Overall	ANTE 1	.	0.813	0.797	0.819	0.823	0.021	-311.2	-296.5	.	0.36	<0.001	0.32	0.3	0.36	0.26	
Day 0		.	0.743	0.733	0.778	0.766											
Day 42		.	0.831	0.83	0.843	0.853											
Day 77		.	0.864	0.854	0.844	0.854											
Day 105		.	0.816	0.771	0.811	0.82											
Overall	ANTE 1	D0	0.84	0.823	0.825	0.841	0.018	-251.1	-243.8	0.035	0.48	<0.001	0.24	0.87	0.124	0.94	
Day 42		D0	0.833	0.836	0.828	0.852											
Day 77		D0	0.867	0.857	0.84	0.853											
Day 105		D0	0.819	0.776	0.807	0.819											
Overall	SPPOW	.	0.813	0.797	0.812	0.818	0.02	-315.1	-310.9	.	0.7	<0.001	0.44	0.61	0.42	0.49	
Day 0		.	0.742	0.733	0.772	0.757											
Day 42		.	0.829	0.832	0.822	0.841											
Day 77		.	0.865	0.853	0.844	0.854											
Day 105		.	0.816	0.771	0.811	0.82											
Overall	SPPOW	D0	0.84	0.824	0.828	0.837	0.018	-248.3	-245.4	0.015	0.74	<0.001	0.27	0.9	0.29	0.79	
Day 42		D0	0.833	0.837	0.839	0.839											

Day 77		D0	0.868	0.858	0.839	0.852										
Day 105		D0	0.819	0.777	0.806	0.819										
Digestible OM intake, kg/d																
Overall	ANTE 1	.	9.07	10	8.13	8.43	0.915	405.8	420.5	.	0.003	<0.001	0.099	0.019	0.37	0.003
Day 0		.	7.01	7.8	7.6	7.5										
Day 42		.	9.28	11.11	9.04	9.51										
Day 77		.	10.1	10.72	7.7	8.94										
Day 105		.	9.91	10.39	8.17	7.78										
Overall	ANTE 1	D0	9.77	10.75	8.24	8.74	0.919	312.2	319.5	0.87	0.003	0.25	0.32	0.01	0.61	0.004
Day 42		D0	9.28	11.15	8.84	9.49										
Day 77		D0	10.11	10.71	7.7	8.94										
Day 105		D0	9.92	10.39	8.17	7.79										
Overall	SPPOW	.	9.09	9.98	8.08	8.05	0.61	409.3	413.5	.	<0.001	<0.001	0.125	<0.001	0.109	<0.001
Day 0		.	7.15	7.8	7.41	7.37										
Day 42		.	9.23	11.19	9.05	9.07										
Day 77		.	10.07	10.53	7.7	7.97										
Day 105		.	9.91	10.4	8.17	7.78										
Overall	SPPOW	D0	9.75	10.69	8.28	8.28	0.722	307.1	310	0.82	<0.001	0.38	0.58	<0.001	0.21	0.001
Day 42		D0	9.25	11.16	8.97	9.07										
Day 77		D0	10.08	10.52	7.7	7.98										
Day 105		D0	9.92	10.4	8.17	7.79										
Digestible energy from OM, MJ/d																
Overall	ANTE 1	.	166.9	184.1	149.5	155.2	16.841	982.4	997.1	.	0.003	<0.001	0.099	0.019	0.37	0.003
Day 0		.	129	143.5	139.8	138										
Day 42		.	170.7	204.5	166.4	174.9										
Day 77		.	185.8	197.2	141.7	164.5										
Day 105		.	182.3	191.3	150.3	143.2										

Overall	ANTE 1	D0	179.8	197.8	151.5	160.8	16.913	737.4	744.7	0.87	0.003	0.25	0.32	0.01	0.61	0.004
Day 42		D0	170.8	205.1	162.6	174.6										
Day 77		D0	186	197	141.7	164.6										
Day 105		D0	182.5	191.1	150.3	143.3										
Overall	SPPOW	.	167.3	183.6	148.7	148.1	11.23	1009.2	1013.4	.	<0.001	<0.001	0.125	<0.001	0.109	<0.001
Day 0		.	131.7	143.5	136.4	135.6										
Day 42		.	169.9	205.8	166.5	166.9										
Day 77		.	185.2	193.8	141.7	146.6										
Day 105		.	182.3	191.4	150.3	143.2										
Overall	SPPOW	D0	179.4	196.7	152.3	152.3	13.286	738.1	741	0.82	<0.001	0.38	0.58	<0.001	0.21	0.001
Day 42		D0	170.2	205.4	165	166.9										
Day 77		D0	185.4	193.6	141.7	146.8										
Day 105		D0	182.5	191.3	150.3	143.3										