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Heritability of roughage intake and dry matter intake in Norwegian Red, and the association with methane emissions

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Animal Science

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Abstract

The need to reduce the agricultural emissions and its environmental footprint has become more pressing in view of its continuing expansion to ensure food security and feed a growing world population. Farm profitability and environmental impacts can be reduced by selecting for lower methane emission and higher feed efficiency in dairy cattle. Projects on measuring methane emission and real feed intake in Norwegian Red (NR) cows are established to examine the relationship between methane emission and feed efficiency. In these projects, Geno has installed GreenFeed units to measure methane emission as well as equipment for monitoring individual roughage intake in commercial dairy herds.

Before implementing these novel traits in the breeding program of NR cows, it remains to be clarified how methane emission and feed efficiency traits are related to each other, which require direct and accurate large-scale measurements of the animals in the environment they are expected to perform in.

From one herd, data were registered daily on methane emission, dry matter-, roughage- and concentrate intake and daily milk yield from a Norwegian barn. Other information available included lactation number, days in milk and week of lactation. Methane data were available for a shorter period and the data foundation were too small to implement genetic analysis of methane. A dataset for methane and feed intake for 42 NR cows were used to analyse phenotypical correlations between methane and feed intake traits. The dataset for methane and feed intake traits contained 4,276 records. Dataset for feed intake traits for 63 NR cows were available from January 1st 2022 and used for genetic analysis of feed intake traits. The data contained 8,561 records. Daily average methane emission, dry matter intake from roughage and concentrate and roughage intake not corrected for dry matter intake is 413.2 grams per day, 19.2 kilograms and 36.3 kilograms, respectively.

Linear regression analysis showed that dry matter- and roughage intake has effects on methane emission, with every kilogram increase in dry matter- or roughage intake, gives an increase in methane emission of 2.8 and 0.6 grams per day, respectively. Phenotypic correlations between methane emission and feed intake traits were estimated to range from 0.15 to 0.25 and 0.25 between methane emission and milk yield. Heritability of dry matter- and roughage intake were estimated to be 0.42 and 0.35, respectively. Results should be interpreted with caution due to a limited dataset.

Further recommendations are analysis of genetic correlations between methane emission and feed intake. Estimates of genetic variation for the whole lactation period or life-span efficiency are needed in order to observe the relationship between feed intake and methane emission in every stage of life and lactation. Another recommendation is that research needs to find the best way to define feed efficiency, in order to draw effective conclusions. Additionally, observations for a larger number of animals are needed for estimation of the genetic relationship between feed intake and methane emission.

Sammendrag

Behovet for å redusere utslipp fra landbruket har blitt viktigere i forhold til landbrukets konstante behov for å ekspandere for å sørge for matsikkerhet og å fø en voksende verdensbefolkning. Det kan være mulig for melkebønder å øke profitt og redusere miljøpåvirkningen ved å selektere for lavere metan utslipp og høyere fôreffektivitet. I dagens samlede avlsindeks på NRF selekteres ikke direkte på verken fôrutnyttelse eller redusert metan utslipp. Forsknings prosjekter som går på å måle metan utslipp og reelt fôropptak i Norsk Rødt Fe (NRF) er startet opp for å undersøke forholdet mellom metan utslipp og fôreffektivitet hos NRF kua, og for å videre undersøke om disse egenskapene kan bli inkludert i avlsarbeidet. I disse prosjektene har Geno installert GreenFeed enheter, i tillegg til utstyr for å måle direkte grovfôropptak på gårder med melkeproduksjon.

Det gjenstår å bli avklart sammenhengen mellom metan utslipp og fôreffektivitet før man kan selektere for egenskapene i avlsarbeidet. Dette krever direkte og nøyaktige stor-skala målinger på dyrene i miljøet de står oppstallet i.

Fra en besetning ble det samlet inn daglig data på metan utslipp, tørrstoff-, grovfôr og kraftfôr opptak og melkeavdrått fra et norsk fjøs. Annen informasjon tilgjengelig inkluderer laktasjonsnummer, dager i melk og laktasjonsuke. Metan data var tilgjengelig kun for en kortere periode og datagrunnlaget var for lite til å gjøre genetiske analyser av metan. Et datasett med metan og fôropptak for 42 kyr ble brukt for å undersøke fenotypiske sammenhenger mellom metan og fôropptak-egenskapene. Datasettet inkludere 4,276 registreringer. Data for fôropptak på 63 NRF kyr var tilgjengelig fra 1.januar og ble brukt til genetisk analyse av fôropptak egenskapene. Datasettet inkluderte 8,561 registreringer. Daglig gjennomsnitt av metan utslipp, tørrstoffopptak fra grovfôr og kraftfôr og grovfôr ikke korrigert for tørrstoff var 413.2 gram per dag, 19.2 kilogram og 36.3 kilogram, henholdsvis.

Linear regresjons analyse viste at tørrstoff- og grovfôr opptak har effekt på metan utslipp, hvor hvert økende kilogram av tørrstoff- og grovfôropptak gir en økning i metan utslipp på 2,8 og 0,6 gram, henholdsvis. Fenotypiske korrelasjoner mellom metan utslipp og fôropptak-egenskaper varierte mellom 0.15 og 0.25, og 0.25 mellom metan utslipp og melkeavdrått. Arvegraden for tørrstoff- og grovfôropptak ble estimert til å være 0,42 og 0,35, henholdsvis. Resultater bør bli tolket forsiktig grunnet begrenset datasett.

Videre er det anbefalt å kartlegge genetiske korrelasjoner mellom metan utslipp og fôreffektivitet. I tillegg er det behov for estimater av genetisk variasjon for hele laktasjons

perioden eller levetiden for å undersøke hvordan forholdet mellom fôropptak og metan utslipp forandrer seg i ulike stadium i laktasjonen og livet. Det er også behov for at forskere kan finne den beste måten å definere fôreffektivitet på for å dra effektive konklusjoner. Observasjoner på flere dyr er også viktig for å undersøke det reelle forholdet mellom fôropptak og metanutslipp.

Content

1.0 Introduction

The need to reduce the agricultural sector's emissions and its environmental footprint has become more pressing in view of its continuing expansion to ensure food security and enough feed to a growing world population (Gerber & Fao, 2013). By 2050 the world population is estimated to grow to 9.6 billion, and the demand for meat and milk is projected to grow by 73 and 58 percent, respectively (Gerber & Fao, 2013), indicating a need for increased livestock production.

However, it was stated that the global livestock sector was responsible for about 18% of total greenhouse gases (GHG) (Steinfeld & Fao, 2006). Among GHGs produced by ruminants, enteric methane is the most impactful contributor with a global warming potential reported by some to be up to 25 times larger than carbon dioxide (Basarab et al., 2013), contributing to climate change of which is a threat to many of the planet's ecosystems and the well-being of current and future generations (Gerber et al., 2010).

Direct measurements of enteric methane production are likely to be challenging and expensive, and the relationship of methane production on other economically important traits are unknown (Basarab et al., 2013). Research suggests one main solution to reduce methane emission in cattle, that is to improve feed efficiency by targeted breeding (Johnson & Johnson, 1995).

Methane production through enteric fermentation is also a waste of fed energy for the animal (Hook et al., 2010). Improving feed efficiency is economically important because feed costs constitute the majority of the variable cost in the dairy industry (Wallén et al., 2017). Direct selection for improved feed efficiency in dairy cattle can contribute to reduced feed consumption, reduce costs and increase resource utilization in milk production, while decreasing methane emission (Wallén et al., 2017).

Norway's agricultural organisations has entered an agreement with the Government. The agreement implies a reduction of almost 5 million tons carbon dioxide- equivalents from the industry's collected emission achieved by 2030. Genos projects (Geno, 2021) on measuring and collecting data on feed efficiency and methane emissions enables feed efficiency to be viewed in context with the cattle's individual differences in methane gas emission from rumen. Data from one of the herds participating in Geno's feed efficiency project was available and included records on individual daily feed intake from roughage and concentrate, and daily methane emissions.

The purpose of this thesis is to describe the relationship between methane emission and feed intake, estimate phenotypic correlations between these novel traits, and estimate heritabilities and breeding values for roughage- and dry matter intake. These are the first heritability estimates for roughage intake on NR cows.

2.0 Literature

2.1 Greenhouse gas emissions in agriculture

It has been estimated that 70% of the methane in the earth's atmosphere is a result of human activity, and agriculture accounts for 60% of this (McDonald et al., 2011). Livestock's Long Shadow stated that the global livestock sector was responsible for about 18% of the total GHG emission (Steinfeld & Fao, 2006), where estimates shows that dairy cattle solely contribute to 4% of anthropogenic GHG emission (Knapp et al., 2014). The dairy production contribution to GHG emission is estimated to be lower in developed countries, due to the higher productivity of livestock agriculture, lack of significant land use change, and the dilution by emissions from other sectors (Hagemann et al., 2011).

The demand for livestock products is predicted to double; an event which will lead to increased GHG emissions from livestock (McAllister et al., 2011). Expansion in livestock production is predicted to occur in the developing parts of the world, where adaption to climate change may be more difficult and opportunities to mitigate emissions is limited. This creates a choice between food shortage and reduced GHG emissions (McAllister et al., 2011). The obvious choice is more food and the implications of this choice for climate change are uncertain.

2.2 Methane

The dairy industry is concerned about methane emission, because international policy discussions have focused on non-carbon-dioxide emissions such as methane since it is less expensive to mitigate than carbon-dioxide emissions (Gerber & Fao, 2013), making methane mitigation approaches both economically advantageous as well as environmentally beneficial (Knapp et al., 2014). However, livestock is considered to be a zero-net source of carbon dioxide since it arises from the metabolism of plant-derived feedstuffs. Hence, the carbon dioxide is a part of a continuously biological cycle with fixation, utilization and exhalation (Gerber & Fao, 2013).

Enteric methane occurs naturally in the digestive system of ruminants as a by-product from enteric fermentation. The rumen provides an anaerobic environment hospitable to microorganisms, which ferment and digest plant material into nutrients that are absorbed by the host (Løvendahl et al., 2018). This commercial relationship has been successful in allowing ruminants and rumen microorganisms to thrive in harsh and widely distributed environments on high cellulose plant diets, which are indigestible for humans and most other animals. The ruminant host cannot survive without the microorganisms and some rumen microorganisms are not found outside of ruminants or are highly differentiated from related microbes (Knapp et al., 2014). During rumen fermentation of organic matter, hydrogen is produced. A surplus of metabolic hydrogen occurs when plant material is transformed to fatty acids. This surplus must be removed by transforming hydrogen to methane by methanogens (McDonald et al., 2011). Methane gas and other gases are then lost to eructation which also represents a loss of 6-10% of the gross energy of fermented food, or 2-12% of feed energy loss (Lan & Yang, 2019).

2.2.1 Methane measurements

The golden standard method for measuring methane for ruminants is respiration chamber (Garnsworthy et al., 2019; Knapp et al., 2014). Most measurements methods only measure oral emission, while respiration chambers measure emission through the oral, nasal and anal routes (Garnsworthy et al., 2019). Respirations chambers have been favoured for their accuracy and low coefficient of variation (Grainger et al., 2007), and is often used to assess the relative worth of an alternative method that may be cheaper, less invasive, easier to implement, or have a wider scope of application (Garnsworthy et al., 2019). Respiration chamber is unsuitable for large scale measurements, since installation costs and running costs are high, and only one animal can be measured at a time. Respiration chambers is an open- or closed-circuit indirect calorimetry where an animal must stay in a period between 2 and 7 days, hence stress can be promoted since the respiration chamber is a new environment for the animal, and they will be separated from their herd at the same time (Garnsworthy et al., 2019). Consequently, it is normal to observe changes in feeding behaviour and drops in feed intake, which will influence the result.

The sulfur hexafluoride tracer gas technique (SF6) was developed in an attempt to measure methane emission from animals without confinement in the respiration chambers (Garnsworthy et al., 2019). Air is sampled near the animal's nostrils though a tube attached to a halter and connected to an evacuated canister worn around the animal's neck or back. A capillary tube or orifice plate is used to restrict airflow through the tube so that the canister is between 50 and 70% full after approximately 24 hours (Deighton et al., 2014). A permeation tube containing SF6 is placed into the rumen, and the pre-determined release rate of SF6 is multiplied by the ratio of methane to SF6 concentrations in the canister to calculate methane emission rate. Animal behaviour and feed intake might be affected by wearing the apparatus, and by daily handling to exchange canisters. However, the technique is considerably less intrusive than respiration chambers, because cows remain in herd (Garnsworthy et al., 2019). A source of error with the SF6 tracer gas technique is that it has not been evaluated if animals share methane emissions when they interact and sampling tube of one animal is near the head of another animal. However, there is good agreement between methane emission measured by the SF6 technique and the gold standard, respiration chamber, although results from the SF6 technique are more variable (Garnsworthy et al., 2019; Grainger et al., 2007; McAllister et al., 2011).

Breath sampling during milking and feeding for large-scale evaluation of methane emission have significant advantages compared with other methods. There has been developed several methods to measure methane concentration in breath for cows during milking and/or feeding, and these are often referred to as "sniffer methods". Air is sampled near the animals' nostrils though a tube fixed in a feed bin and connected directly to a gas analyser (Garnsworthy et al., 2019). Breath sampling methods are non-invasive because once installed, animals are unaware of the equipment, and they remain in their normal environment. There is no need for a change in the animals' daily routine, nor need for handling, training or change of diet. However, results are more variable because the concentration of gasses in the sampled air are influenced by cow head position relative to the sampling tube (Huhtanen et al., 2015).

GreenFeed (C-Lock Inc., Rapid City, SD, USA) is a sophisticated sniffer system where breath samples are provided when animals visit a bait station (Huhtanen et al., 2015). GreenFeed samples breath from individual animals several times per day for short periods (Garnsworthy et al., 2019). GreenFeed is a portable standalone system used in barn and pasture applications and incorporates an extractor fan to ensure active airflow and head position sensing for representative breath sampling (Hammond et al., 2016a). Measurements are pre-processed by the manufacturer, and data are available in real time through a web-based data management system (Hammond et al., 2015). A limitation to this system is that animals require training to use the system, although animals which have been trained to use the system will readily use it again. However, some animals will not use it or will use it infrequently, and frequency is affected by diet (Hammond et al., 2016b). Another challenge is that results can be affected by distance from the animal and pointing angle.

2.2.2 Between animal differences

Cattle can produce 250 to 500 L of methane per day (Johnson & Johnson, 1995), which indicate that methane production or methanogenesis varies among individuals (Herd et al., 2002). Between-animal variation in methane emissions can be attributed to a variety of factors, including individual differences in rumen microbiome, digestive functions and metabolic regulation, and the interaction between these factors (Løvendahl et al., 2018), diet (Vlaming et al., 2008) and animal physiology (Cabezas-Garcia et al., 2017).

Methane yield can change, in association with physiological drivers affecting intake (Pinares-Patiño et al., 2007). Differences between individual animals in plant selection during grazing, host-microbe interaction, and rumen digesta retention rates may be heritable and thus amenable to genetic selection for animals with lesser enteric methane emission. However, poor repeatability for methane measurements and high within-animal variation limits selection (Vlaming et al., 2008).

2.2.3 Challenges with genetic selection for methane

Little information has been available on opportunities to mitigate enteric methane thorough animal genetics, but potential has been proved (de Haas et al., 2011). Now, more recent studies have found that there is substantial genetic potential for reducing methane emission from dairy cows by breeding (Wethal et al., 2021). Heritability estimates for methane varies between 0.16 to 0.25 (Lassen & Løvendahl, 2016; Wethal et al., 2021; Zetouni et al., 2018). Studies have indicated that substantial between-animal variance exist for the trait (Johnson & Johnson, 1995; Nkrumah et al., 2006), and that variation in enteric methane was present between animals and breeds, and across time (Herd et al., 2002). Direct methane measurements under practical conditions are challenging (de Haas et al., 2011) and costly, but possible. Another possibility is to improve methane emission through selection on traits that are genetically correlated or are proxies for methane emission, i.e., feed efficiency. It has been claimed that animals with favourable feed efficiency eat less than their contemporaries for the same level of production and that because methane production is proportional to dry matter intake, improving feed efficiency should reduce methane production (Yan et al., 2010).

2.3 Feed efficiency and feed intake

Feed is the biggest variable cost in dairy production. Feed efficiency depends upon an animal's ability to transform ingested feed into metabolically available nutrients (Løvendahl et al., 2018). Methane is synthesized from hydrogen and carbon dioxide, both of which otherwise could be used for formation of volatile fatty acids (VFAs). If the loss of dietary energy in the form of methane is reduced, it may increase feed efficiency and ultimately lead to an increase in milk production. Direct selection for dairy cattle with improved feed efficiency can contribute to reduce feed consumption and costs and increase resource utilization in milk production. This will reduce GHG emissions and the rate of nutrient losses (Connor, 2015).

2.3.1 Definitions and measurement methods for feed efficiency

Efficiency is often defined as the ratio of output over input or its inverse (Korver, 1988; Løvendahl et al., 2018). Feed efficiency in dairy cattle is influenced by diet and other environmental factors, genetic ability, and physiological state of the cow to utilize nutrients for milk yield. Multiple terms have been used to define feed efficiency in lactating cows. A often used definition is based on feed conversion efficiency; a trait-based ratio calculated as energy-corrected milk (ECM) per kilogram dry matter intake (DMI) (Hurley et al., 2016). Another one is gross feed efficiency (GFE), expressed as the ratio of milk output to feed input. Total milk output is normalised to milk components such as solids- or energy-corrected milk yield and feed input is expressed either as DMI or energy intake (Connor, 2015). Another term to define feed efficiency of dairy herds examines efficiency directly from a profitability standpoint and is referred to as income over feed cost or return over feed (ROF) (Connor, 2015). ROF is calculated as the difference between the total revenue obtained from the sale of milk during a selected time interval and the feed costs associated with its production. This profit indicator is dependent upon fluctuating milk prices and the cost of feed ingredients and is therefore difficult to calculate. A more common measure of feed efficiency is residual feed intake (RFI). RFI is calculated as the difference between the actual feed intake and predicted feed intake, based on a model that accounts for energy costs for body maintenance and production over a particular production period (Løvendahl et al., 2018). Because RFI represents a difference between actual feed intake and predicted feed intake required to support maintenance and production, a low or negative RFI value is desirable. Shifting focus from cost to income, dry matter intake (DMI) and energy corrected milk (ECM) can exchange positions in the RFI model to obtain estimated residual milk yield (RMY). RMY is the deviation in milk yield at a constant feed intake, adjusted for metabolic body weight (MBW), and liveweight (Løvendahl et al., 2018).

Despite large contribution to the variable costs of milk production (Dillon et al., 2008), feed intake is not directly included in international dairy breeding objectives, although genetic responses in feed intake are expected through the inclusion of correlated traits such as milk production (Van Arendonk et al., 1991). As a first step on the way to develop feed efficiency as a trait for NR, roughage- and dry matter intake are being analysed. Dry matter- and roughage intake is a function of meal size and meal frequency that are determined by animal and dietary factors affecting hunger and satiety (Allen, 2000). Feed intake in cattle is moderately heritable and selection for its improvement would theoretically be effective (Korver, 1988). Applying a positive weighting to dry matter intake, or a correlated trait in a breeding objective will enhance the rate of genetic response in dry matter intake (Veerkamp, 1998).

2.3.2 Between animal differences

Individual cows differ in their ability to digest various feedstuff (Cabezas-Garcia et al., 2017; Huhtanen et al., 2015). Small improvements can, on a large scale, provide substantial value (Løvendahl et al., 2018). Nutrient intake of the dairy cow is used for different biological processes such as milk production, maintenance, growth and foetus (Korver, 1988). Variation exist between animals appetite, digestion and nutrient absorption, maintenance requirement, utilization of metabolizable energy for production, nutrient partitioning and output composition (Korver, 1988). Studies have shown that selection feed efficiency, defined as RFI, should be accompanied by a reduction in methane production, and it was suggested that cattle selected for better feed efficiency, or low RFI, produce 15% less enteric methane (Herd et al., 2002). Cattle with better feed efficiency consume less feed than expected for growth, production and maintenance (Herd et al., 2002).

2.3.3 Challenges with genetic selection for feed utilization

The greatest obstacle to assessing feed efficiency is individual measurements on each cow. Practical and cost-effective means to evaluate feed efficiency among commercial production herd are therefore needed (Connor, 2015). Automated feed monitoring systems are available, however, there has earlier been difficulties with measurement collection for larger groups because of limited feeding capacity (Connor, 2015). Today, Geno and CRV is measuring real feed intake in dairy cattle with measuring equipment installed in Norwegian and Dutch barns (CRV, 2022; Geno, 2021). Large scale measurements will enable genetic selection for improved feed utilization.

Another obstacle is discordances in results due to different trait definition (Løvendahl et al., 2018). The relationship between feed efficiency and methane emission is likely to be a biased reflection when either or both are expressed as ratios. It was suggested that it would be prudent to include the components of the ratio, each associated with its own appropriate weighting, in a selection index (Løvendahl et al., 2018).

2.4 The association between feed intake and methane emission

Methane is often assumed to represent a loss of energy, and thereby a drag on efficiency (Løvendahl et al., 2018). Meaning, methane measurements could be useful as an indicator of energy loss and, by extension, efficiency. Efficient cows produce more milk relative to the amount of feed ingested and energy lost as methane as less efficient cows (Knapp et al., 2014). One methane mitigation strategy is increasing animal production through genetics (Knapp et al., 2014). Improving nutrient utilization for productive purposes to dilute out maintenance on an individual animal on herd basis, increasing feed efficiency and decreasing methane per unit of product. Production efficiency can be improved by genetic selection and management practices that address not only nutrition and feeding, but also reproduction, heat stress tolerance, disease incidences, culling rates, and heifer replacement programs (Knapp et al., 2014).

Selection for either feed efficiency or limited methane emission could create a favourable correlated response in the other trait. Enteric methane from dairy cattle is positively phenotypically associated with DMI and feed intake (Basarab et al., 2013; Grainger et al., 2007). When feed intake increases, additional substrate is available for rumen fermentation

(Basarab et al., 2013), hence more hydrogen available for methanogenesis (Grainger et al., 2007). No relationship between methane and feed intake were detected in lactating Holstein, Simmental or Jersey cows (Münger & Kreuzer, 2008). However, favourable relationships between RFI and methane production were reported for lactating Nordic Red cattle (Negussie et al., 2014).

Both methane emission and feed conversion efficiency (FCE) are heritable traits for dairy cows. Both traits are, to some degree, thought to be influenced by the composition of the rumen microbe (Løvendahl et al., 2018). There are indications of a favourable correlation between methane emission and FCE, whereby more efficient cows may be emitting less methane per kg milk.

2.4.1 Other factors affecting methane production

Other factor indirectly reducing methane emission per kilogram product are lifetime production. Genetic approaches that improve health, disease resistance, reproduction, and tolerance to heat stress will lead to increases in individual lifetime and herd productivity and indirectly reduce methane emissions per unit of milk (Knapp et al., 2014). Genetic selection for milk yield, energy efficiency, disease resistance, and heat tolerance will result in reductions in enteric methane, through increased milk yield, dilution of maintenance feed costs, and reduced need for replacement animals (Knapp et al., 2014). Approximately 50 to 55% of the increase in milk yields under intensive management has been achieved by genetic selection, and the remainder through improvements in management practices (Hansen, 2000; Knapp et al., 2014). Animals cannot reach their full genetic potential if factors in their environment are limiting. Management practices that enhance the ability of individual cows to increase milk yield and reach their genetic potential include practices to reduce nonvoluntary culling and diseases, facility and equipment designs to improve the cows' environment, and use for performance-enhancing technologies, as well as improvements to improve profitability as well as decrease methane emission (Knapp et al., 2014).

Methane production can be affected by feed. Substances added to the food to decrease methane production include halogen analogues of methane. However, their effects tend to decrease over time as the rumen bacterial population adapts to their presence (McDonald et al., 2011). Ionophore antibiotics decrease methane production and increase propionate formation and probiotics are also beneficial. Attempts to alter the microbial population in the rumen have not been successful due to the varied population and the capacity of the organisms to adapt (McDonald et al., 2011). High quantities of concentrate increase the production of propionate and reduce methane as a result of the less favourable environment for the methane-producing bacteria. However, there are drawbacks from this approach in that the animal is more susceptible to acidosis and the use of cereals compete directly with humans (McDonald et al., 2011). Only 3% of the overall Norwegian areal is topsoil, where 31% of these are used for cereal production (Bondelag, 2022).

2.5 Genos research project

Geno started a three year long project on feed efficiency in 2021 (Geno, 2021). The project is named selection for improved feed efficiency for NR. Measurement equipment has been installed in collaborating Norwegian barns and shall register real roughage feed intake. Direct selection for cows with improved feed efficiency can contribute to reduced feed consumption, reduce costs, and increase resource utilization in milk production (Geno, 2021). Breeding for improved feed efficiency is expected to have great economic effect for the Norwegian farmer. Calculations shows that a 1% reduction in feed consumption will have a potential cost reduction on 41 million NOK per year (Geno, 2021).

Another ongoing project on NR, project climate friendly cow, aim to examine if there is possible to breed for a more climate friendly cow (Geno, 2021). Equipment has been installed in Norwegian herds to measure individual methane- and carbon dioxide emissions. The goal is to collect knowledge on how best to reduce GHGs through breeding.

These ongoing research projects makes it possible to study associations between feed efficiency and methane emission (Geno, 2021). More knowledge is needed of the association between these two traits. This should make a strong fundament for the development of a sustainable and climate- and environmental-friendly dairy cow, both national and international (Geno, 2021).

In this thesis, the first data available on both methane emission and feed intake for one herd from these projects are used to calculate heritability of dry matter- and roughage intake, calculate phenotypic correlations between feed intake and methane emission for this herd.

3.0 Materials and methods

3.1 Data

Data were available from one of the herds participating in the feed efficiency project. The herd is located in Jessheim. These cows were housed in a freestall barn under commercial conditions. Cows were born between 2013 and 2020.

Methane massflux is measured in the GreenFeed automate while the animals are served concentrate. The GreenFeed was installed in April, and from every visit to the GreenFeed station, measurements of methane and carbon dioxide that the cows are producing are provided in grams per day. For each cow, methane measurements at each visit were averaged per day and each cow retained one value of produced methane in gram per day. In total 14.352 observations were available for methane production, with an average of 107 visits every day.

Roughage intake were collected from feeding mangers with scale from BioControl (the CRFI systems – controlling and recording feed intake). The dataset contains 595,785 registrations in total before editing the data. Roughage intake measurements from each visit in a day were summarized to intake per day. In average, the feeding stations had 2,327 visits every day. Data from the days 31.12.2021, 01.01.2022, 31.02.2022 and 02.01.2022 were removed from the dataset because of unlikely high observations, ranging around 50 to around 115 kilograms of roughage per cow per day. Additionally, 960 observations before January 1st were removed because of start-up problems in the beginning of the registration period. Feeding samples were collected from the roughage every month. Samples were sent to Eurofins and dry matter content (DM) were analysed. In both May and June, there were two roughage-analyses available because of a feeding experiment and cows were fed to diets with and without seaweed. Information about which cows that were fed seaweed additives was not included in this thesis, therefore the mean DM content of the two feed-analyses were used as input value for the respective month. In table 1, dry matter content of the roughage for each respective month is listed:

Table 1. Monthly dry matter percentage (DM %) of the roughage feed-analysis.

Month	**DM%**
January	31.7
February	31.2
March	31.8

April	39.9
May	42.8
June	39.7
July	42.9

Data for concentrate intake contained 17,538 observations. Data were summarized to one record per cow per day. Dry matter content in concentrate was 0.881 or 88.1% analysed by Eurofins.

Data for daily milk yield measured in kilograms contained 40,657 observations. For each cow, milk yield measurements at each milking were summarized to one daily observations per cow. The milking robot had on average 111 daily visits.

Other information on cows, such as date of birth, pedigree and calving information was extracted from the Norwegian Dairy Herd Recording System. A pedigree file for the animals in the current study contained 808 observations with relationship traced back to their great grandparent generation.

From these data collections, two final datasets were made that was used for the analysis. It was set a requirement for all the data, that observations for all variables had to be registered on the same date. Only records with known animal ID were kept.

The following variables were used to identify cattle and merge observations from the different datasets;

- RFID-number: RFID stands for radio frequency identification and is an identification number in the animal’s electronic ear tag.
- Animal number: identification number (4-digit ear tag number) which is usually the four last digits in the RFID-number.

Dataset 1 contained observations on 42 animals with data on both methane and feed intake in the period 08.04.2022 to 26.06.2022. Variables of interest in dataset 1 were;

- Date: date of each observation
- Methane (g/d): methane massflux exhaled from the animals, average per cow per day
- Roughage intake (kg): roughage eaten in kg summarized per cow per day
- Concentrate intake (kg): concentrate eaten in kg summarized per cow per day

- Dry matter intake (DMI): Total DMI from concentrate and roughage per cow per day
- Milk yield (kg): milk yield in kilograms per cow per day
- Birthyear: the year the cow was born
- Lactation-number: cows lactation number on observation day
- Lactation-group: group 1= first lactation, group 2= second lactation, group 3= lactation 3 or more
- DIM: days in milk (days between day of observation and calving date)
- Week of lactation: DIM/7

Feed intake were also analysed from a dataset without methane registrations because feed intake were recorded over longer time. Hence, dataset 2 contained observations for 63 animals in the period 01.01.2022 to 26.06.2022. Otherwise, the variables of interest in dataset 2 were the same as in dataset 1.

3.2 Statistical analysis and modelling

R-Studio (RStudio, 2020) were used for data analysis. The following additional packages were used;

- tidyverse: editing datasets
- ggplot2: construction of figures
- lubridate: making dates recognizable
- dplyr: manipulate data
- ggpubr: data visualization
- grid: plotting within data
- grid.Extra: provide functions to grid
- corrplot: provides visual exploratory tool on correlation matrix
- RColorBrewer: provides colour schemes
- sjPlot: collection of plotting and table output functions for data visualization
- sjlabelled: collection of functions dealing with labelled data
- sjmisc: supporting data transformation tasks
- lme4: fits linear and generalized linear mixed-effects models

3.3 Phenotypic correlations to methane

Phenotypic correlations were calculated as Pearson correlation coefficient (r) in R-Studio. Pearson correlation coefficient describes the strength and direction of the linear relationship between two quantitative variables, where -1 is strong negative correlations, 0 is no correlation and 1 is strong positive correlations.

The phenotypic correlations were calculated between methane, feed intake traits and daily milk yield.

3.4 Mixed Models

The following mixed linear model below was used to examine associations between methane and feed intake;

$$Methane_{ijklm} = b1*X + b2*week\ of\ lactation_i + lactation\ number_j + animal_k + testday_l + e_{ijklm}$$

where,

$methane_{ijklm}$ is the m^{th} record of methane in gram per day for cow k on testday l.

b1 is a regression coefficient, for the linear regression of X on methane, where X is either DMI which is a total dry matter intake in kilograms per day for cow k on testday l (X_1) or roughage which is a roughage intake in kilograms per day for cow k on testday l (X_2).

B2 is a regression coefficient, for the linear regression of week of lactation on methane.

Lactation number j is number of lactations in classes where 1 is first lactation, 2 is second lactation and 3 is 3 lactations or more (j=1, 2, or 3 class).

$Animal_k$ is the random effect of animal k.

$Testday_l$ is the random effect of day of observation.

e_{ijklm} is the residual.

3.5 Genetic analyses of feed intake traits

Variance components, heritability's, and breeding values for dry matter- and roughage intake were estimated with the following linear animal models in DMU (Madsen & Jensen, 2013);

$y_{ijklm} = week\ of\ lactation_i + testday_l + lactation\ number_j + animal_k + e_{ijklm}$

where,

y_{ijklm} is either DMI which is a total dry matter intake in kilograms per day for cow *k* on testday *l* or roughage which is a roughage intake in kilograms per day for cow k on testday l.

Week of lactation *i* is stage in lactation in weeks (60 classes).

Testday$_l$ is the fixed effect of day of observation *l*.

Lactation number *j* is number of lactations in classes where 1 is first lactation, 2 is second lactation and 3 is 3 lactations or more (j=1, 2, or 3 class).

animal$_k$ is the additive genetic effect linked to a pedigree file.

e_{ijklm} is the residual.

Variance components for random effect of animal (σ^2_a) and residual (σ^2_e) were estimated and the corresponding heritability was calculated as;

$h^2 = \sigma^2_a / \sigma^2_a + \sigma^2_e$.

Breeding values and solutions for fixed effects were given in solution file (.SOL-file) from DMU.

4.0 Results

4.1 Descriptive statistics

The distribution of daily methane emission is illustrated in figure 1, with a mean ± standard deviation of 413.2 ± 87.5. The median of the distribution is 411.6 grams methane per day. In figure 2, daily emitted methane over time is illustrated.

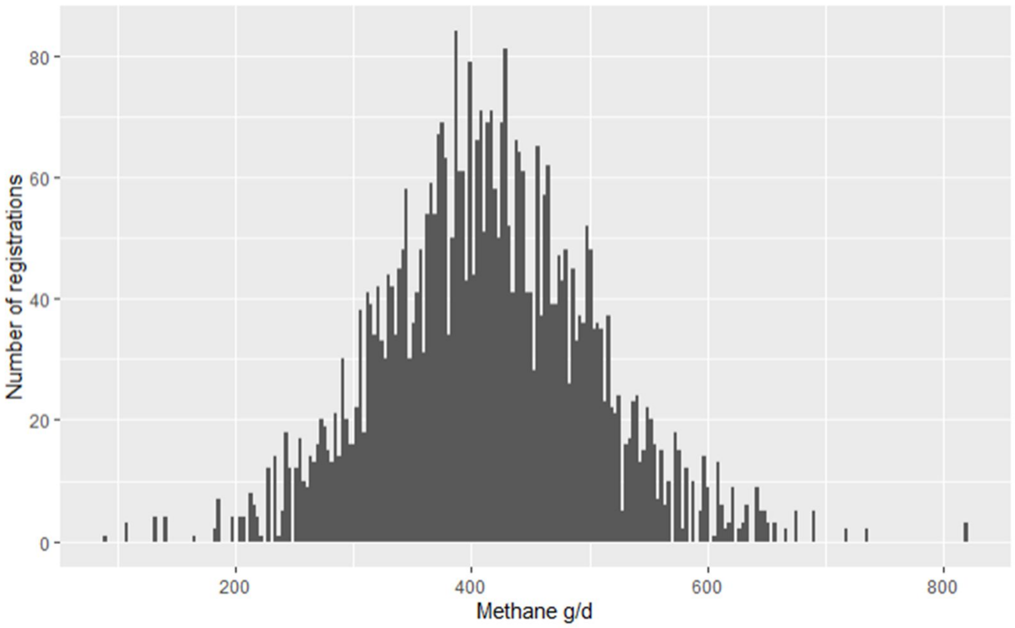

Figure 1. Distribution of methane emission measured in grams per day (g/d) from 42 Norwegian Red cows in GreenFeed.

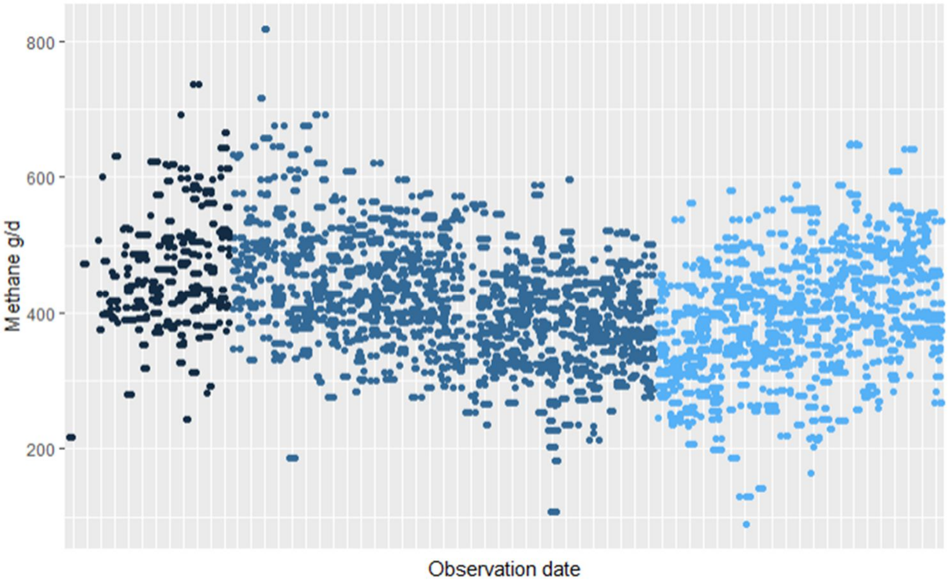

Figure 2. Plot of methane emission in grams per day (g/d) over time, where the darkest blue represent April 2022, and the lightest blue represent June. Registrations on 42 Norwegian Red cows in GreenFeed.

The distribution of total dry matter intake from roughage and concentrate is shown in figure 3, with a daily average ± standard deviation of 19.2 ± 3.7 kilograms per day. Median for the distribution is 19.2 kilograms DMI per day. In figure 4, daily dry matter intake over the period with data is illustrated.

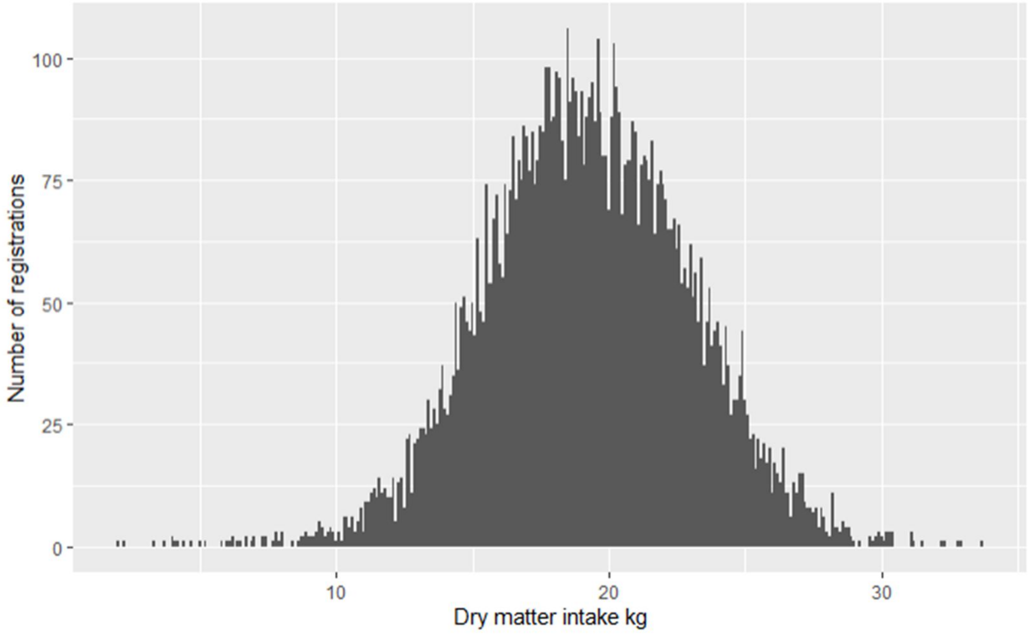

Figure 3. Distribution of dry matter intake (DMI) measured in kilograms (kg) per day for 63 Norwegian Red cows. Total DMI from both roughage and concentrate.

Figure 4. Plot of total dry matter intake (DMI) from roughage and concentrate measured in kilograms (kg) per cow per day over time for 63 Norwegian Red cows, where the darkest blue represent January2022, and the lightest blue represent June 2022. For every change in colour, a new month is plotted.

The distribution of roughage intake not corrected for dry matter content is illustrated in figure 5, with a daily average of 36.3 ± 9.0 kilograms per day. Median for the distribution is 36.2 kilograms roughage per day. In figure 6, roughage intake over time is illustrated.

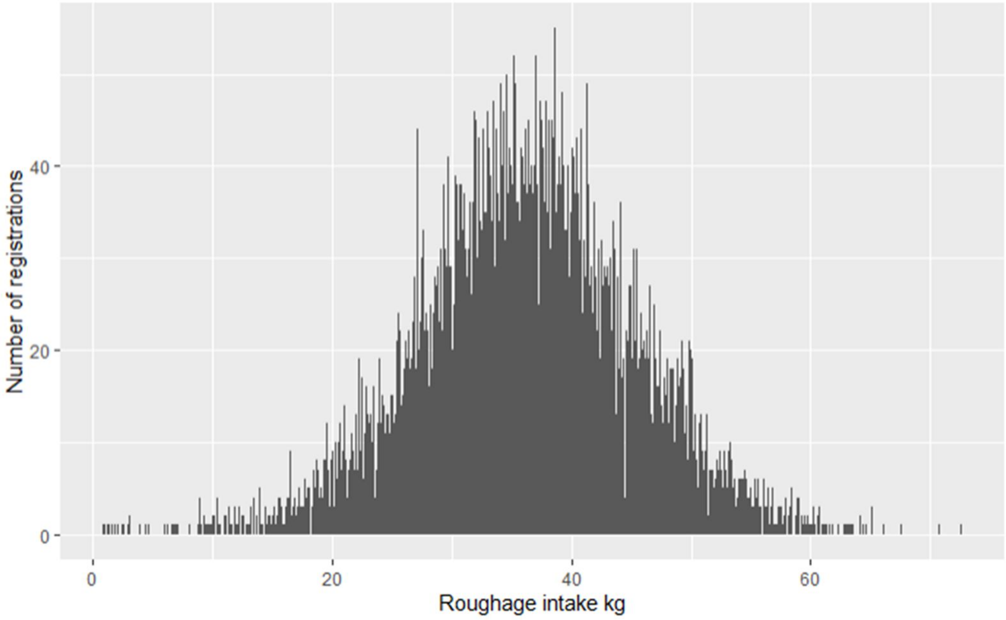

Figure 5. Distribution of roughage intake measured in kilograms (kg) per cow per day, for 63 Norwegian Red cows. Not corrected for dry matter content.

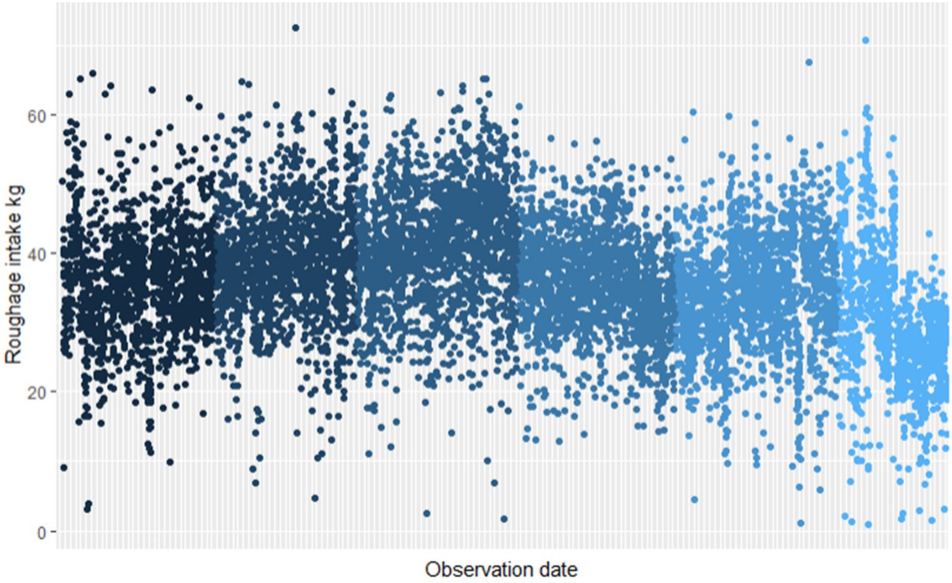

Figure 6. Plot of roughage intake measured in kilograms (kg) over time for 63 Norwegian Red cows, where the darkest blue represent January 2022, and the lightest blue represent June. For every change in colour, a new month is plotted.

The distribution of daily milk yield is illustrated in figure 7, with a mean of 28.5± 9.9. The median of the distribution is 27.6 kilograms milk per day. In figure 8, daily milk yield over time is illustrated.

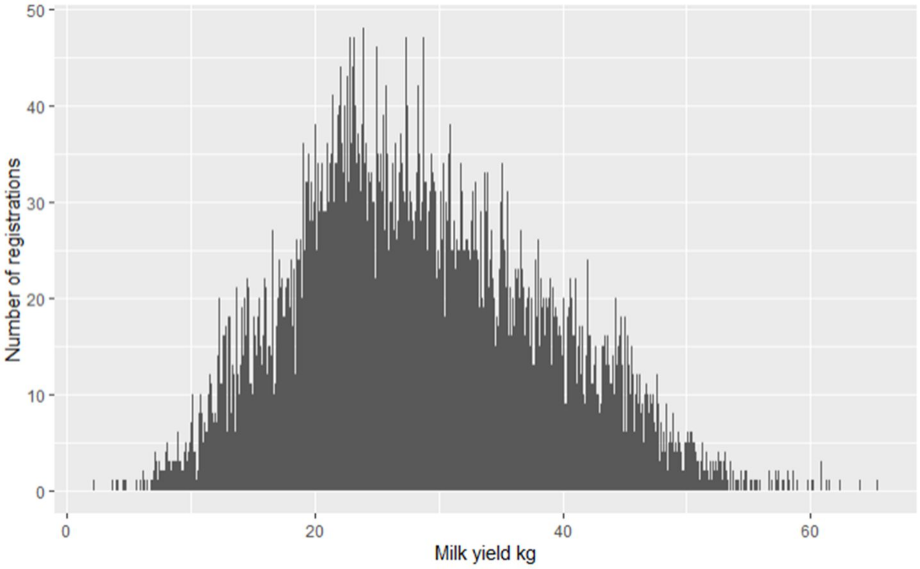

Figure 7. Distribution of daily milk yield measured in kilograms (kg) for 63 Norwegian Red cows.

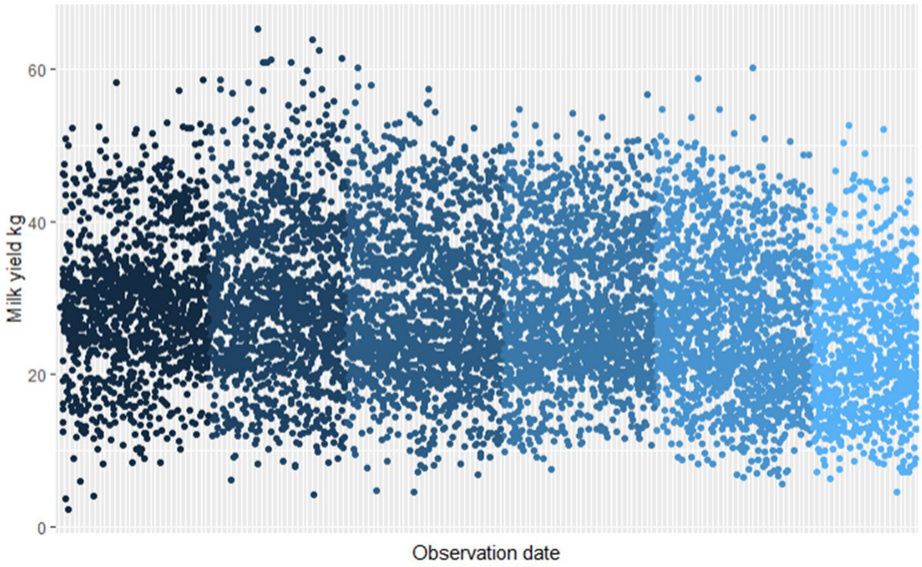

Figure 8. Plot of milk yield measured in kilograms (kg) over time for 63 Norwegian Red cows, where the darkest blue represent January, and the lightest blue represent June. For every change in colour, a new month is plotted.

The relationship between dry matter from roughage and dry matter from concentrate in kilogram is illustrated in figure 9.

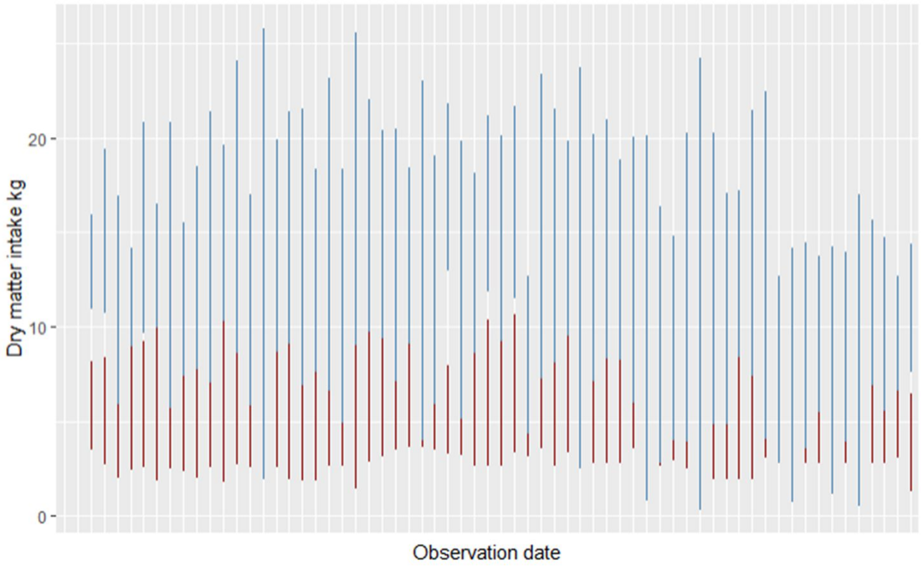

Figure 9. The relationship between dry matter from roughage (shown in blue) and dry matter from concentrate (shown in red) measured in kilograms between January and June, for 63 Norwegian Red cows.

4.2 Phenotypic correlations methane

Correlation was obtained from dataset 1 to measure to what extent feed intake traits and milk yield are linearly related with the cow's phenotypic level of methane emissions. Traits that were included for phenotypic correlations were dry matter-, roughage- and concentrate intake and milk yield. Dry matter intake and milk yield correlates the highest with methane emission (r=0.25). Concentrate- and roughage intake correlates moderately phenotypically with methane emission, with values of 0.20 and 0.15, respectively.

4.3 Methane and feed intake

The linear regression analysis showed that for every unit increase in dry matter intake, methane emission increased with 2.8 grams per day. The model also estimated that for every week increase in week of lactation, methane emission increased with 0.9 grams per day indicating a linear connection. Lactation number also had effect on methane. Cattle in second lactation emitted on average 28.0 grams per day more than cattle in first lactation, while cattle in third lactation or more emitted on average 19.3 grams per day more than cattle in first lactation. Day of observation accounted for 29.1% of the variance in methane emission, while the animal accounted for 35.1% of the variance.

The analysis of methane and roughage showed that for every unit increase in roughage intake, methane emission increased with 0.6 grams per day. For every week increase in week of lactation, methane emission increased with 0.8 grams per day, indicating a linear connection. Cattle in second lactation emitted on average 33.0 grams more per day than cattle in first lactation, while cattle in third lactation or more emitted on average 22.0 grams more per day than cattle in first lactation. Day of observation accounted for 27.7% of the variance in methane emission, while the animal itself accounted for 37.6% of the variance for this model.

4.4 Genetic analysis of feed intake traits

Estimated variance components for daily total dry matter intake- and roughage intake are presented in table 2. All estimates were significant different from 0, and heritabilities were large. Heritability was estimated to be 0.42 for dry matter intake, and 0.35 for roughage intake.

Table 2. Estimated variance components with standard error (SE) and heritability (h^2) for daily total dry matter intake (DMI) estimated in DMU, for 63 Norwegian red cows.

	DMI		**Roughage**	
Variance component	**Estimate**	**SE**	**Estimate**	**SE**
Variance for additive genetic effect	3.46	0.65	17.59	3.35
Residual variance	4.81	0.75	32.16	0.50
Phenotypic variance	8.27	0.05	49.75	0.04
Heritability	0.42	0.05	0.55	0.04

Breeding values for total daily dry matter- and roughage intake are illustrated in figure 10 and 11. Both figures illustrate large variation in predicted breeding values for the traits. Predicted breeding values for total daily dry matter intake in figure 10 shows lowest value of -3.0 and highest predicted breeding value of 5.7. Figure 11, for daily roughage intake, shows the lowest breeding value of -8.9 and highest breeding value of 9.1. The mean breeding values for total daily dry matter- and daily roughage intake were estimated to be -0.07 and 0.02, respectively.

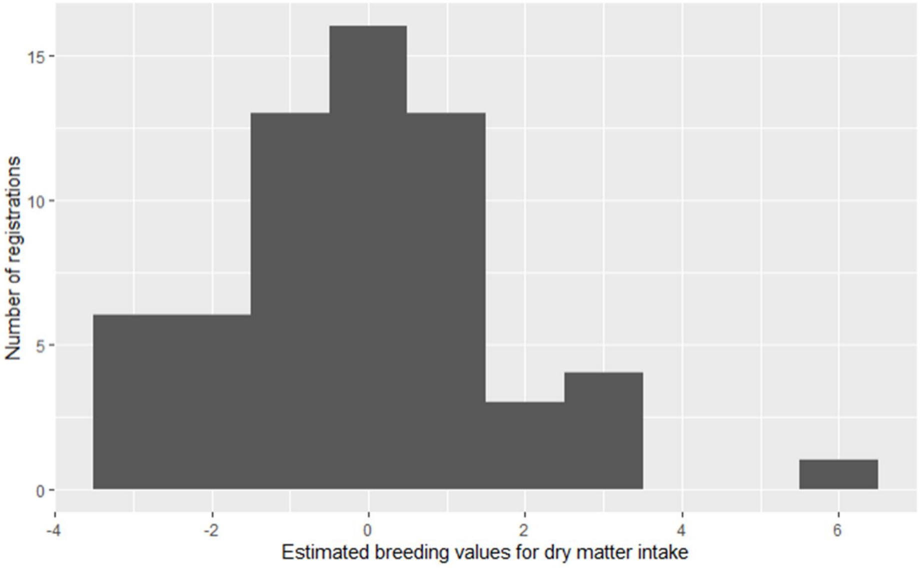

Figure 10. Breeding values for dry matter intake (DMI) measured in kilograms (kg) for 63 Norwegian Red cows based on phenotypic data on daily feed intake measured individually in mangers, in addition to data on concentrate intake from feeding stations.

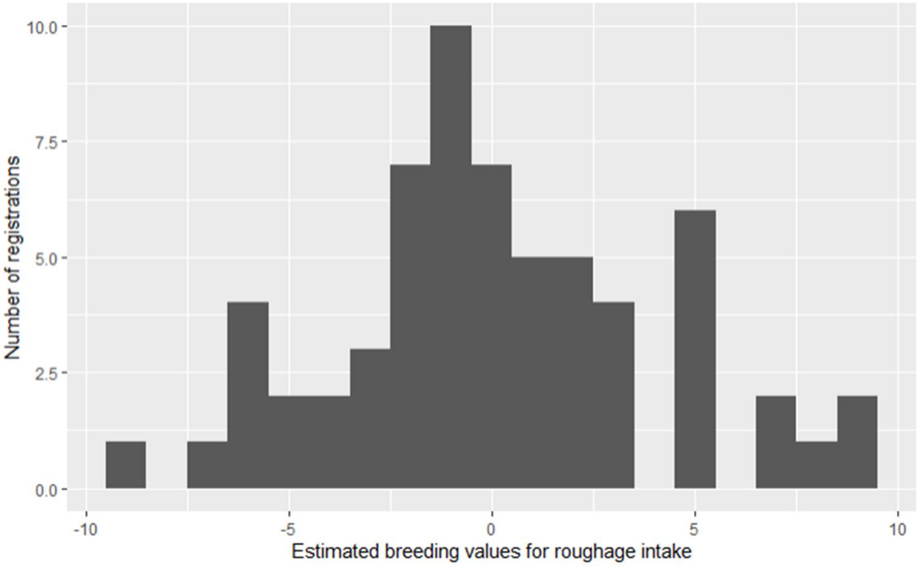

Figure 11. Breeding values for roughage intake measured in kilograms (kg) for 63 Norwegian Red cows based on phenotypic data on daily feed intake measured individually in mangers.

4.5 Fixed effects solutions

Solutions for fixed effect of week of lactation on dry matter- and roughage intake are given in figures 12 and 13. In figure 12, dry matter intake is highest at the beginning of lactation and decrease further in the lactation. In figure 13, roughage intake increases from the beginning of lactation and reaches a top in week 40. From there, roughage intake decreases rapidly.

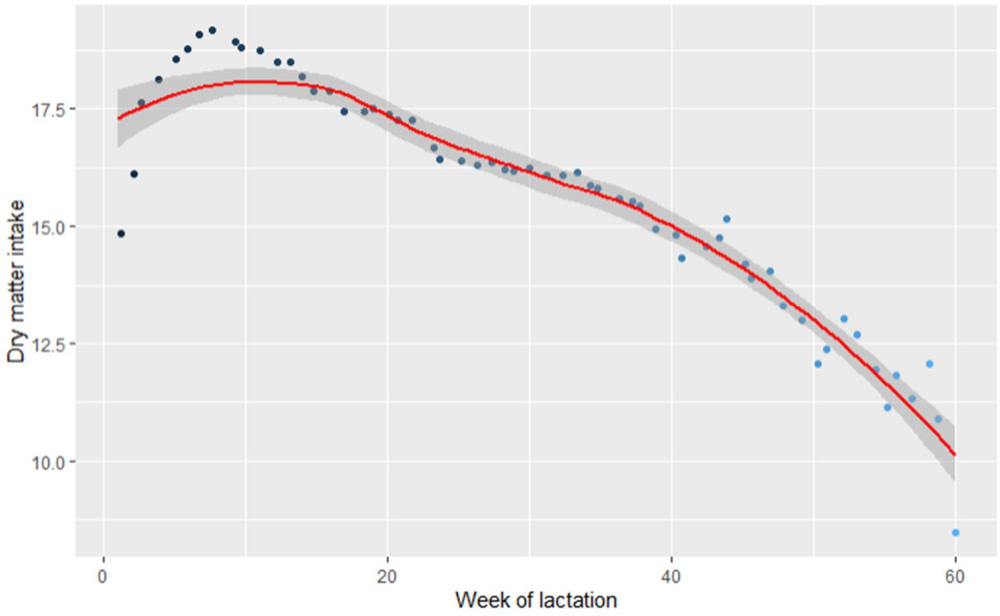

Figure 12. Solutions for fixed effect of week of lactation on dry matter intake (DMI) measured in kilograms per day. The standard error varied between 0.6 and 1.3 Trend line is shown in red.

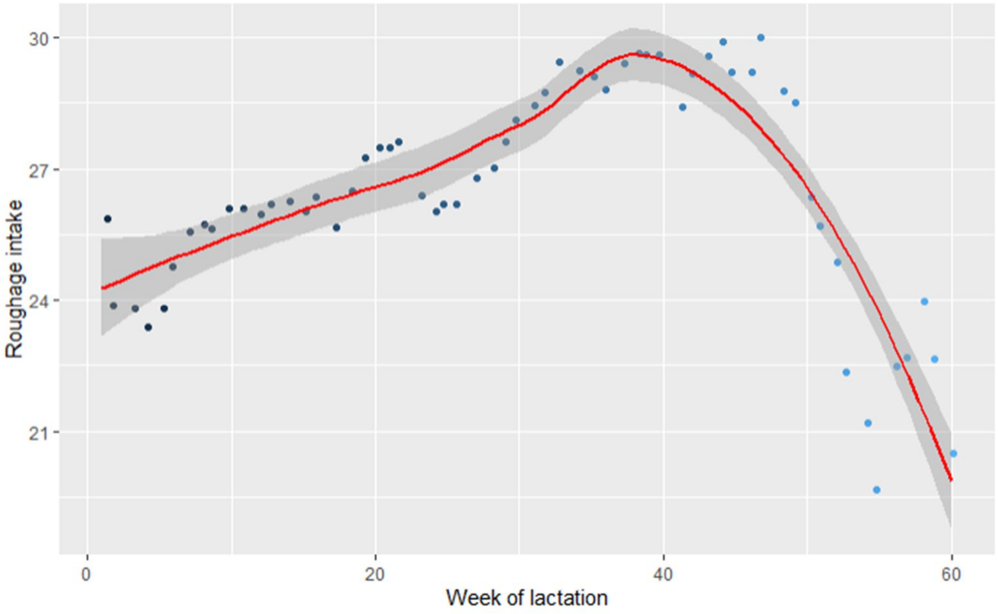

Figure 13. Solutions for fixed effect of week of lactation on roughage intake measured in kilograms per day. The standard error varied between 1.4 and 3.3. Trend line is shown in red.

Effects of testday on dry matter- and roughage intake are illustrated in figures 14 and 15. Observations were registered between January and June, and testday 1 represents January 1st. Figure 14 shows that dry matter intake drops around February-March before intake increase again to reach a top around April. A second drop appears around May. Figure 15, show that roughage intake increases until around March, before intake decreases.

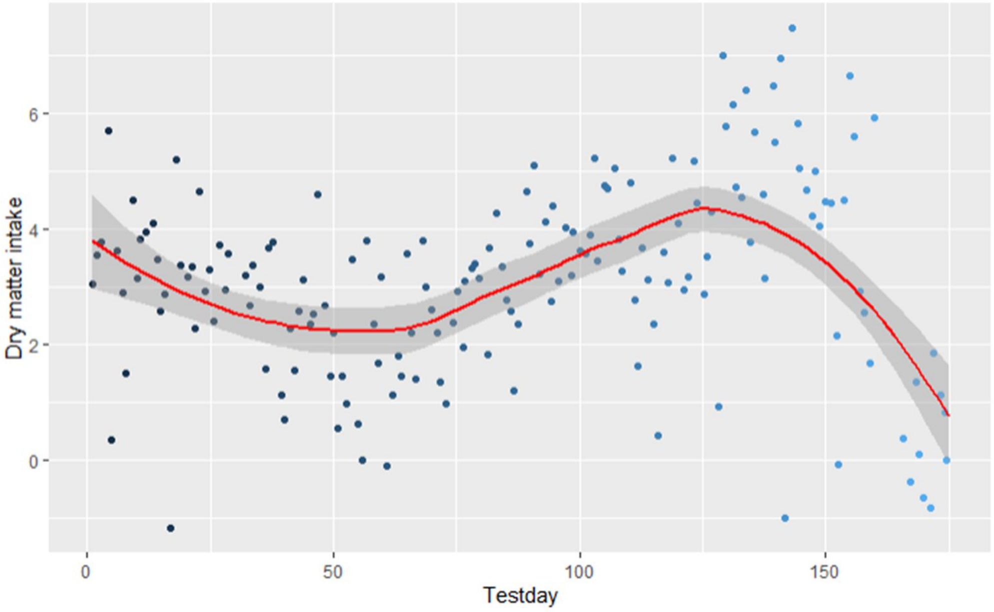

Figure 14. Solutions for fixed effect of testday (day of observation) on dry matter intake measured in kilograms per day. The standard error varied between 0.0 and 0.5. Trend line is shown in red.

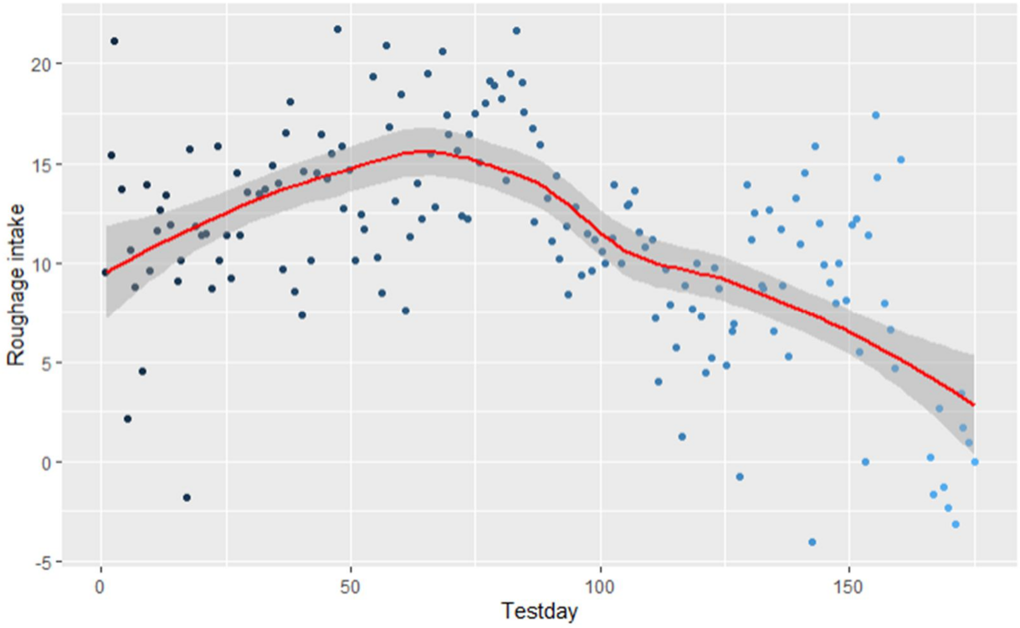

Figure 15. Solutions for fixed effect of testday (day of observation) on roughage intake measured in kilograms. The standard error varied between 0.0 and 1.3. Trend line is shown in red.

Effect of lactation number is shown in Table 3. The overall effect of number of lactations is bigger for roughage intake.

Table 3. Solutions for fixed effects of lactation number (where 1= first lactation, 2=second lactation, and 3= 3 or more lactations) on roughage and dry matter measured in kilograms. The standard error varied between 0.5 and 0.3 for DMI, and between 1.1 and 0.8 for roughage.

Lactation number	**DMI**	**Roughage**
1	-2.9	-5.3
2	0.2	-1.4
3	0.0	0.0

5.0 Discussion

5.1 Descriptive statistics

Research on methane production for dairy cattle has been challenging because of the limited opportunities on reliable registrations in a large-scale. However, new technologies such as the GreenFeed has made better possibilities for research Methane observations in this herd were approximately normally distributed with a mean of 413.2 ± 87.5 g/d. Such values agrees with earlier observations made on dairy cattle, where the mean and standard deviation were found to be 327 ± 49 on Friesian x Jersey measured with SF6 tracer technique (Pinares-Patiño et al., 2007), and 469 ± 81 on Australian cattle with the SF& technique (Richardson et al., 2021). Figure 3, 5 and 7 illustrates that results are in line with expected values for dry matter intake, roughage intake and milk yield (Melk, 2022). Figure 2 can indicate that there is seasonal variation in methane production for the cattle. However, the time period for the observation is too short to say anything about the actual trend or if there is significant effect of seasons. Figure 4, 6 and 8 shows some seasonal variation as well for dry matter intake, roughage intake and milk yield, respectively, but the time period for the observations are too slim to observe the actual seasonal variation.

5.2 Phenotypic association

Evidence exist that DMI is key driver for methane emissions from animals offered confined diets (Ellis et al., 2007), concentrate feeding, which normally results in an increase in total DMI (Jiao et al., 2014), explaining why DMI has bigger effect on methane than roughage intake in the current study. However, another study found that neither daily methane production nor methane production per kilogram of milk produced were affected by concentrate feed level (Young & Ferris, 2011). Another study found that whereas methane production per kilogram of milk was unaffected by concentrate supplementation, methane production per kilogram FCM decreased with increasing concentrate feed level (Lovett et al., 2005). The relationship between DMI and enteric methane has been extensively studied and is well-established (Hristov & Melgar, 2020). The relationship has been predicted to be linear and highly correlated (r=0.94) (Kriss, 1930), and it has been shown that DMI alone can be successfully used to predict methane emission both in dairy cattle (Niu et al., 2018) and beef cattle (van Lingen et al., 2019). Another study estimated phenotypic correlations between DMI and methane production, methane yield, and methane intensity to be 0.49 ± 0.04, −0.27 ± 0.05, and −0.11 ± 0.05, respectively (Richardson et al., 2021). The current study estimated a moderate correlation (r=0.25) illustrated in table 2, indicating that methane emission increases with increasing DMI. Previous studies revealed that the strength of the relationship between DMI and methane emission may depend on the methane measurement technique; the relationship was good (R^2=0.58) for respiration chamber, but poor (R^2=0.05) when methane production was measured using the GreenFeed system (Hristov et al., 2018; Niu et al., 2018).

Studied further, it was concluded that the relationship between enteric methane emission measured using GreenFeed and DMI in dairy cattle depends on the time of measurement relative to the time feeding (Hristov & Melgar, 2020). This may explain the lower effect of DMI on methane emission in the current study, compared to some other studies.

It has been observed a low correlation between roughage intake and methane emission in the current study (r=0.15), while the correlation is moderate between methane emission and concentrate intake were estimated (r=0.20). As mentioned earlier, DMI is key driver for methane emissions from animals offered confined diets (Ellis et al., 2007), concentrate feeding, which normally results in an increase in total DMI (Jiao et al., 2014). This could be the explanation why concentrate feed correlates higher with methane emission, than roughage intake.

At the beginning of lactation, intake of nutrients, especially energy and protein, does not meet requirements of the high-yielding dairy cow (Korver, 1988), explaining high values for both dry matter- and roughage intake in the current study. Then, cattle will enter a negative energy balance. Body energy, rather than energy from DMI, is used for milk production. Therefore, in early lactation, the correlation between milk yield and methane production can be negative because no methane is produced from the body energy thus used. Consequently, cattle can reach a negative energy balance and is associated with infertility (de Haas et al., 2017). This results in an increased number of animals to maintain production, which will increase methane at herd level. Later in lactation, energy for milk production originates from DMI, resulting in methane production. This leads to positive correlations between milk yield and methane production. However, positive genetic correlation between methane production and milk yield are expected because the increase in the genetic potential of animals to produce more milk increases methane emission per animal because of an increase in feed consumption (Ghavi Hossein-Zadeh, 2022; Lassen & Løvendahl, 2016). This is also the case for the current study, where methane emission and milk yield are moderately correlated (r=0.25). Earlier studies have estimated moderate genetic correlations between milk- and methane-production (Breider et al., 2019; Garnsworthy et al., 2012), with correlations ranging from 0.38 to 0.57 (Breider et al., 2019).

5.4 Genetic analysis of feed intake traits

Heritability estimates of feed efficiency have been varying, and many of them show what is described as a low-to-moderate heritability (de Haas et al., 2011). Studies estimated the heritability of feed efficiency, as RFI, to be between 0.01 up to 0.40 (Basarab et al., 2013; Coleman et al., 2010; Connor et al., 2012; de Haas et al., 2011). Published estimates of the heritability of FCE in dairy cattle reported estimates of 0.37 (Van Arendonk et al., 1991), and 0.14 to 0.21 (Vallimont et al., 2011), indicating that selection for FCE in dairy cattle is feasible (Pryce et al., 2014).

Heritability estimates for DMI has shown similar highly varying results. One study estimated heritability of 0.07 (Toshniwal et al., 2008), while another study estimated a far greater heritability of 0.61 (Veerkamp et al., 2000). A third study supports such ranging values, with heritability estimates for predicted DMI ranging between 0.12 and 0.53 (de Haas et al., 2015). In the current study, heritability for DMI was estimated to be 0.42. Other studies have reported heritability estimates ranging from 0.13 to 0.54 for dry matter intake (Koenen & Veerkamp, 1998; Veerkamp, 1998; Veerkamp & Thompson, 1999). Suggesting that if measurable, or correlated to an easily measured trait, genetic selection for increased dry matter intake will be worthwhile (Berry et al., 2007). Another study found similar results, where heritability estimates for DMI varied from 0.10 to 0.30 (Berry et al., 2007). Care must be taken when selecting for energy balance (EB) of which DMI is a component trait, due to its association with impaired fertility both phenotypically and genetically (Veerkamp et al., 2000).

5.5 Fixed effects solutions

Dry matter intake, illustrated in figure 12, starts with around 17.5 kilograms of methane in week 0, and slowly decreases through the lactation. Roughage intake, illustrated in figure 13, starts at around 24 kilograms, and increases until week 40, before it drops rapidly. It could be expected that roughage intake should be highest in the beginning of lactation, and not at week 40. However, it is thinkable that high concentrate intake in the beginning of lactation contributes to a substitution effect and thus lower roughage intake. Gradually, as the concentrate level decreases throughout the lactation, roughage intake increases.

In figure 14, dry matter intake drops around February-March before intake increase again to reach a top around April. A second drop appears around May. In figure 15, roughage intake increases until around March, before intake decreases. Meaning that while roughage intake increases, dry matter drops. Naturally, when cattle increase roughage intake, concentrate intake will decrease. Concentrate feeding normally results in an increase in total DMI (Jiao et al., 2014), thus DMI will decrease with increasing roughage intake.

The observed substitution effect between concentrate intake and roughage intake is confirmed in plot 9, where the relationship between dry matter from roughage and dry matter from concentrate is plotted. The plot illustrates lower values for roughage when values are higher for concentrate feed, and vice versa.

5.6 Concerns; the need to lower methane emission while improving feed efficiency

Researcher William Cline sees the reduced potential for agricultural production as the greatest consequence of climate changes. Based on his modelled effects of expected climate changes, the agricultural activity in the world could decline with 3 to 16 percent (Smedshaug, 2012). He states that some countries may not be affected negatively if the temperature arises with “only” 2 degrees. Tropical areas will get reduced yield from the soil, while temporized areas will get increased productivity (Smedshaug, 2012). However, a temperature increase between 4 to 6 degrees will have strong unpredictable effects and will also reduce the potential in temporized countries (Smedshaug, 2012).

In many countries, livestock are not used simply as food, but also for cultural purposes, as draft power and for financial security. Thus considering livestock solely a source of food in effort to plan the nature of future animal population system is a grave error (McAllister et al., 2011).

Reduced emissions of GHGs is necessary to limit the increase in global temperature, holding it below two degrees Celsius and to avoid threatening climate change (Gerber & Fao, 2013). The need to decrease GHG emissions has been in focus in many sectors, including the global livestock. There are a lot of research on GHG emission related to dairy cattle, and with Genos ongoing projects, more knowledge will be uncovered.

Estimated correlations between methane production and other traits, except for milk yield, have been reported as unsignificant or low (Breider et al., 2019; de Haas et al., 2011; Kandel et al., 2013; Zetouni et al., 2018). In the current study, there were found moderate correlations between methane emission and dry matter- and concentrate intake.

The need for long-lasting measures that gives long-lasting changes in emission and production of environmental gases are crucial. This thesis is only a small part of a bigger project. There will be useful to continue measuring methane emission and feed efficiency from NR in Norwegian barns to obtain results on a large-scale level with more animals over a longer period of time.

5.7 Assumptions and limitations

There is potential for error in every part of the processing of data material. This is important to consider when interpreting results. The dataset for roughage intake registrations contained some strange values. Unlikely high values were registered for four days, and the dataset contained what is believed to be start-up problems with unlikely low registrations in the beginning of the test period. These days were filtered out from the analysed dataset. It is also possible that errors can occur in the GreenFeed. Human errors like miscalibration or long timeframes between each calibration can result with deviations in results. However, it is assumed that such errors are minimal.

6.0 Conclusion

Dry matter-, roughage- and concentrate intake has moderate effects on methane emission. Correlation between methane emission and dry matter- and concentrate intake were moderate, while the correlation between methane emission and roughage intake were weak. Heritability estimated of dry matter- and roughage intake were high.

Short timeframes and few animals can give inaccurate estimates of feed efficiency and methane emission. Results should therefore be interpreted with caution. Large-scale measurements with timeframes who reflect the whole lactation period or life-span efficiency are needed.

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