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Effizienzmerkmale in der Rinderzucht

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Eidesstattliche Erklärung

Ich erkläre hiermit eidesstattlich, dass ich die vorliegende Arbeit selbstständig angefertigt, keine anderen als die angegebenen Hilfsmittel benutzt und alle aus ungedruckten Quellen, gedruckter Literatur oder aus dem Internet im Wortlaut oder im wesentlichen Inhalt übernommenen Formulierungen und Konzepte gemäß den Richtlinien wissenschaftlicher Arbeiten zitiert und mit genauer Quellenangabe kenntlich gemacht habe.

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1 Einleitung

In den letzten Jahrzehnten ist die Milchleistung der Kühe deutlich angestiegen. Gleichzeitig sanken Nutzungsdauer, Fruchtbarkeit und Gesundheit (KNAUS 2009). Seit 1950 hat sich in Österreich die durchschnittliche Milchmenge per Laktation von 2.998 kg auf 7.281 kg mehr als verdoppelt (ZAR 2016). Die Nutzungsdauer sank hingegen ebenso wie in anderen Ländern z. B. in den USA und Bayern unter vier Laktationen (KNAUS 2009). Nach ESSL (1982) wurde damit der Grenzwert für die Kosteneffektivität der Kühe unterschritten. Der 1995 in Österreich eingeführte Zuchtwert für Nutzungsdauer gebot diesem Abwärtstrend Einhalt (FUERST und EGGER-DANNER 2002). Für Fleckvieh und Braunvieh war die tatsächliche Nutzungsdauer in den letzten 15 Jahren stabil bis leicht steigend (FÜRST et al. 2019). Zudem häufen sich Beobachtungen einer stetigen Zunahme der Körpergröße der Tiere (z. B. KROGMEIER 2009). Dies lag in den USA an der Annahme, dass größere Tiere mehr Milch geben (HANSEN 2000). VEERKAMP (1998) beschreibt aufgrund der Auswertung zahlreicher Studien eine genetisch positive Korrelation zwischen Lebendmasse und Milchleistung. Unzureichende Messungen, die Mobilisation von Körpergewebe, oder uneinheitliche Erhebungszeitpunkte dieser Studien überlagern jedoch den Zusammenhang und führen zu oft widersprüchlichen Ergebnissen. In den USA führten züchterische Langzeitstudien (z. B. MAHONEY et al. 1986, HANSEN et al. 1999, BECKER et al. 2012) zu größeren und schwereren Tieren mit höheren Gesundheitskosten. Die schweren Kühe produzierten auch nicht die meiste Milch (BROWN et al. 1977). Sie weisen jedoch einen höheren Erhaltungsbedarf (GfE 2001) auf. GRUBER (2013) errechnete auf Basis der Nährstoffversorgungsempfehlungen der GfE (2001), dass Kühe durchschnittlich um 832 kg ECM (energiekorrigierte Milch) mehr leisten müssen, wenn ihre Lebendmasse um 100 kg ansteigt, um die gleiche Nährstoff-Effizienz zu erreichen (4,75 MJ NEL pro kg ECM). Nach GRUBER et al. (2004) erhöht sich die Gesamtfuttermittelaufnahme pro kg Milchleistung jedoch nur um 0,22 kg. Dies erfordert eine höhere Energiekonzentration für die Deckung des zusätzlichen Nährstoffbedarfes, oder die Tiere müssen verstärkt auf ihre Fettreserven zurückgreifen (STEINWIDDER 2009).

Aufgrund der hohen Futterkosten in der Milchwirtschaft (DE HAAS et al. 2014) wird Effizienzmerkmalen immer mehr Beachtung geschenkt. Milchleistung, Futteraufnahmekapazität, das Ausmaß an Mobilisation von Körpergewebe und die Aufteilung der Nährstoffe zwischen Milch und Körper zählen zu den Hauptursachen der genetischen Variation der Energie-Effizienz (VEERKAMP und EMMANS 1995). Besonders bei hochleistenden bzw. milchbetonten Tieren und in der frühen Laktation förderte die züchterische Betonung der Milchleistung katabole Stoffwechselprozesse durch eine davon entkoppelte und unzureichende Futteraufnahme (MARTENS 2013). Die somatotrope Achse regelt die Aufteilung der Nährstoffe zwischen Milch und Körper durch das milchleistungsfördernde Wachstumshormon (Somatotropin, GH) und den insulin-ähnlichen Wachstumsfaktor-I (IGF-I) (LUCY et al. 2009). Eine hohe Milchbetonung hebt die Gegenregulierung des Wachstumshormons in der frühen Laktation aus (Insulinresistenz). Dies verstärkt wiederum die Mobilisationsvorgänge. Neuere Studien (z. B. RINGSEIS et al. 2015) verbinden die dabei freigesetzten freien Fettsäuren (NEFA) mit Entzündungserscheinungen und Stress im Endoplasmatischen Retikulum der Leber. Wie die Literatur zeigt, erstreckt sich die wissenschaftliche Auseinandersetzung mit Nährstoffaufnahme, Lebendmasse, Milchleistung und deren Relationen (Effizienzmerkmale) z. T. über viele Jahrzehnte. Relativ neu hingegen sind die Erkenntnisse zu den durch die Züchtung betroffenen Stoffwechselvorgängen. Gleiches gilt auch für die tatsächli-

che züchterische Anwendung von Effizienzmerkmalen. Eine Zucht auf Effizienzmerkmale führt zu leichteren, aber stark mobilisierenden Tieren und dadurch ebenfalls zu den damit verbundenen Gesundheits- und Fruchtbarkeitsproblemen (VALLIMONT et al. 2011).

Die Rinderzucht Austria initiierte 2012 das Projekt „Efficient Cow“, um Effizienzmerkmale zu entwickeln und Auswirkungen auf die Treibhausgasemissionen zu prüfen. Ein möglichst ganzheitlicher Blick auf Effizienz und damit verbundene Merkmale wie Futteraufnahme, Milchproduktion, BCS, Lebendmasse sowie Gesundheits- und Fruchtbarkeitsmerkmale ist dafür notwendig (s.o. VALLIMONT et al. 2011).

In Rahmen dieses Projektes verfolgt die vorliegende Studie folgende Ziele:

1. Beschreibung der Futteraufnahmeschätzung mit Daten von landwirtschaftlichen Betrieben unter Berücksichtigung des Fütterungssystems
2. Beschreibung der Rationszusammensetzung nach Fütterungssystem und Grundfutterkomponenten
3. Beschreibung des Einflusses von Genotyp, Laktationszahl und Laktationsstadium auf Futteraufnahme, Nährstoffaufnahme, Milchleistung, Energiebilanz, Effizienzmerkmale, Lebendmasse und BCS
4. Beschreibung der Zusammenhänge zwischen Effizienz und kataboler Stoffwechselsituation (Energiebilanz)
5. Beschreibung des Einflusses der Lebendmasse auf ausgewählte Effizienzmerkmale abhängig vom Genotyp
6. Beantwortung der Frage, ob eine optimale, genotypabhängige Lebendmasse für die höchste Effizienz existiert und in welchem Bereich die untersuchte Population liegt
7. Schätzung genetischer Parameter für Effizienzmerkmale und deren Zusammenhang zu BCS und Lahmheit
8. Entwicklung eines Schätzmodelles für die Lebendmasse mittels Körpermaßen, BCS oder Bemuskelung und Validierung

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2 Wissenschaftliche Publikationen

2.1 Efficient Cow – Estimation of feed intake for efficiency traits using on-farm recorded data

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Efficient Cow – Estimation of feed intake for efficiency traits using on-farm recorded data

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2.1.1 Abstract

Increasing efficiency is necessary to cope with scarce resources and higher costs especially for energy and concentrate. The Federation of Austrian Cattle Breeders (ZAR) started the project "Efficient Cow" in 2013 to evaluate efficiency traits in cattle breeding under Austrian conditions. Data of approximately 5,400 cows, i.e. 3,100 Fleckvieh (dual purpose Simmental), 1,300 Brown Swiss, 1,000 Holstein kept on 167 farms were recorded over a whole year. Feed intake was predicted by a model considering animal and ration specific parameters. The observation of the individual feeding information considering the variety of feeding systems and ration compositions was the biggest challenge. A novel data encoding system for ration components was established to reflect different on-farm feeding situations correctly and to ensure a successful and structured further processing for intake prediction. A total of 1,960 different rations could be reduced to 16 different feeding systems and therefore calculation methods depending on the way ration components were offered, namely mixed together, separately or without known amount or proportion in diet like pasture.

KEYWORDS: cattle breeding, efficiency, phenotypes, dairy cows, feed intake prediction, on-farm data collection

2.1.2 Introduction

Increasing efficiency is necessary to cope with scarce resources and higher prices especially for energy and concentrate, but also when prices for products are under pressure. Because total costs in dairy production consist of feed costs for more than 50% (de Haas et al. 2014), feed efficiency is an important part to increase herd profitability. Feed efficiency is however only one aspect of efficiency. Efficiency should also include aspects of health, fertility and longevity. Over the past decades milk production and body size of dairy cows has increased (Krogmeier 2009). Heavier cows have to produce more milk to be as efficient as smaller cows. But feed intake capacity did not develop in parallel with milk production. Therefore higher concentrate diets are necessary to meet demand. Steinwider (2009) calculated a proportion of concentrate of 18% for a cow with 550 kg but of 27% for a cow with 850 kg. In case of insufficient nutrient supply, a

negative energy balance especially in early lactation leads to a higher risk for diseases and infertility (Martens 2012).

Results of a survey among Austrian dairy farmers 2012 (Steininger et al. 2012) revealed their rising interest in health and efficiency traits. Beside this the discussion about greenhouse gas emissions was another reason for starting the project “Efficient Cow” in Austria in 2012, headed by the Federation of Austrian Cattle Breeders (ZAR).

As the possibilities of recording efficiency related traits in research herds are limited in Austria, the project aims at on-farm recording. Aside from that a reasonable number of animals also enables genetic analyses of the new defined efficiency traits. Because of the lack of individual measurements of feed intake, novel strategies for recording and estimating feed intake had to be developed considering the big variety of diet composition and feeding systems in Austria. Furthermore information of characteristics of diets and of feed and nutrient intake is essential for modelling greenhouse gas emissions. This paper focuses on the methodical way from data collection to the feed intake prediction models.

2.1.3 Material and Methods

2.1.3.1 Data Collection

The Federation of Austrian Cattle Breeders (ZAR) initiated the project "Efficient Cow" at the end of the year 2012 with a one-year data collection in 2014. The objective of “Efficient Cow” was to develop efficiency parameters in cattle breeding considering Austrian circumstances. Efficiency combines already used traits like milk, beef, health and functional traits, and other traits which are relevant for feed efficiency. Therefore beside data, which are included in the routine performance recording, additional parameters like live weight, body measurements and parameters describing diets, feed quality and health were collected at each performance testing during the whole year 2014. Data of nearly 5,400 cows (3,100 Fleckvieh – dual purpose Simmental, 1,300 Brown Swiss, 1,000 Holstein) kept on 167 farms were collected. Farms were selected to cover the diverse production environments in Austria ranging from mountainous regions to intensive farms in climatically favourable regions. Despite this, the herd size with 32.6 cows is approximately twice as high as the Austrian average (Steininger et al. 2015).

2.1.3.2 Feeding systems and parameters

The observation of the individual feeding information considering different feeding systems and ration compositions was the biggest challenge. The information on ration composition needs to be structured in such way that it can be used for feed intake estimation with the prediction model no. 1 of Gruber et al. (2004). This equation considers, inter alia, the influence of forage quality (NEL_{Forage} , MJ NEL kg DM⁻¹) and of the total amount of concentrate (kg cow⁻¹) in the diet.

The amount of concentrate can be measured relatively accurately, if it is offered separately per automation, but less precisely if it was offered manually. Despite these inaccuracies, the separately fed amounts of concentrate were assumed to be fed without residues. The challenge was to find a method to calculate the concentrate intake, if a total mixed ration (TMR) or partial mixed ration (PMR) is fed. The amount of concentrate depends on the intake of mixed ration, but at the same time the intake of mixed ration depends on the total amount of concentrate. So

methods to calculate concentrate supplementation had to be developed depending on the type of ration (TMR, PMR, separately supplemented concentrate SEP) and special characteristics.

Another challenge was to integrate farmers' statements that a little amount of forage had been fed separately to the main (mixed) ration. For example, 1 kg hay was scattered over the TMR (80% forage, 20% concentrate) to motivate cows to eat more. This separately offered component must not be integrated into the remaining mixed ration if calculating feed intake. Strictly speaking, this ration is not a TMR anymore, but the way to calculate feed intake is equal to a TMR combined with a special formula to integrate the separately fed forage. Therefore in this study such a ration is still understood as TMR but with a special calculation module. So the amount of the separated hay is assumed to be known like the separately fed concentrate, but the intake of the TMR is depending on individual parameters like milk yield and live weight and is therefore estimated with the feed intake model considering the hay. These separately fed amounts of a ration component are defined as "fixed" components. Fixed components are assumed to be eaten without feed residues, so that the accurate amount is not an unknown variable. Contrary to these fixed parts of ration, feed intake of the 80% forage and 20% concentrate of the TMR is not known, but it can be estimated because of the known composition of the mixed ration. The ratio of forage intake of the fixed components to the total forage intake makes it possible to weight and mathematically express NEL_{Forage} now considering both, mixed and fixed forage components in the total ration.

The third challenge was to handle components, where no amount or proportion was recorded. For example the diet consists of pasture with supplementation of preserved food. The offered and known amounts of preserved food are too much, as that they can be assumed to be eaten fix. The ratio of pasture to preserved food is unknown. This constellation of ration components led to the introduction of "ad lib"-components. Here the ratio of offered mixed forage components to the potential mixed forage intake was used to assume a ratio for NEL_{Forage} calculation. Therefore the data had to be expressed in kg cow^{-1} .

So the ration components were partitioned into mixed, fixed and ad lib components, which describe the component type. Each main feeding system (TMR, PMR and SEP) can thus be modified with a fixed and/or ad lib forage component. The simplest diet consists only of mixed forage components. Overall, 16 different combinations of the component types mixed forage, mixed concentrate, fixed forage and fixed concentrate and ad lib forage were defined. So a standard TMR only consists of mixed forage and mixed concentrate, the PMR has additionally fixed concentrate, and a SEP only mixed forage and fixed concentrate. The encoding of the ration components according their component type reflects the different feeding systems and diets of the dairy cows in a transparent way.

To ensure high data quality, completed forms of the farmers had to be checked across different farm types and dates within each farm before finally entering data into the database. Implausibilities were clarified directly with the farmers or the person responsible for the on-farm data collection. The following data had to be recorded:

- start date of ration and used concentrate mixtures
- three feeding groups: lactation, additional high lactation if necessary and dry cows
- feeding system: TMR, PMR and SEP

- component type: mixed, fixed and ad lib components
- category of forage considering botanical origin (grassland, legumes, forage maize, straw), conservation (hay, silage, fresh) and number of mowing
- concentrate composition (proportion of barley, wheat, ...)
- commercial compound feed and nutrient content
- feed samples for analysis of forage in the laboratory for feed analyses of the chamber of agriculture in Austria
- individual amount of concentrates fed separately from forage (kg/cow and day)

2.1.3.3 Estimation of feed intake

The individual daily feed intake estimation was conducted in cooperation with the Austrian Agricultural Research and Education Centre Raumberg-Gumpenstein.

As individual feed intake was impossible to measure on-farm, the total feed intake (DMI) prediction model no. 1 for separated concentrate supplementation of Gruber et al. (2004) was used for calculation:

$$DMI = 3,878 + Country \times Breed + Parity + Day\ in\ Milk + b_{BW} * BW + b_{Milk} * Milk + b_{Concentrate} * Concentrate + 0,858 * NEL_{Forage}$$

This empirical model considers the fixed effects of breed and country, management level, parity, stage of lactation depending on day in milk and the regression coefficient for the energy content of forage (NEL_{Forage}). Depending on the day in milk the regression coefficients for body weight (b_{BW}), milk performance (b_{Milk}) and for amount of concentrate ($b_{Concentrate}$) have to be calculated. This shows the influence of the stage of lactation on milk performance, live weight and on forage substitution (Gruber et al. 2004).

The original model no. 1 only covers diets, where concentrate is supplemented separately from forage. For calculating with a TMR and PMR, the input parameters concentrate amount had to be expressed mathematically depending on feed intake, concentrate proportion in mixed ration (mixed concentrate) and separately fed fixed concentrate. If the ration additionally had a fixed forage component, NEL_{Forage} had to be expressed according the characteristics of the feeding system.

The adaption of the chosen equation was preferred to take advantage of the high coefficient of determination ($R^2 = 86.7\%$) and the low residual standard deviation ($RSD = 1.32\text{ kg DM}$) compared to prediction model no. 5 for TMR ($R^2 = 83.5\%$, $RSD = 1.46\text{ kg DM}$) (Gruber et al. 2004). Jensen et al. (2015) evaluated the up-to-date feed intake models of NRC (2001), of Volden et al. (2011), TDMI-Index (Huhtanen et al. 2011), Wageningen-DCM (Zom et al. 2012a, 2012b) and TMR-Model no. 5 (Gruber et al. 2004) for dry matter intake by dairy cows fed TMR and found the Gruber model to be the most accurate one.

2.1.4 Results and Discussion

Approximately 1,960 different diets were recorded, 1,932 were potentially relevant for intake estimation, but under consideration of data quality, only 1,890 could finally be used for further processing. On the whole 1,260 forage analyses were available for calculating the nutrients of 570 forage components without analyses. This method ensures site- and management adapted

assumptions of nutrients instead of using tabulated data. Approximately 2,280 different feeds including 1,830 forage components and 438 concentrates as well as compound feeds were needed for describing the diets. Finally the 1,960 diets could be reduced to 16 different feeding systems due to the possible combinations of the component types. For each feeding system another mathematical adaption of feed intake model had to be developed. These numbers show the diversity and complexity of feeding systems and ration compositions of the present investigation. For this reason a prediction model had to be chosen, which reflects ration composition and forage quality parameters besides animal individual factors like parity, stage of lactation, live weight and milk yield.

Furthermore estimation should be individual and as accurate as possible to enable calculation of efficiency traits. The feed intake equation by NRC (2001) considers similar animal related criteria, but not feed-specific parameters like forage quality or concentrate level. The feed intake model by Volden et al. (2011) belongs to a semi-mechanistic feeding model and represents a fill-factor system. It combines the feed intake capacity, which is determined by live weight, stage of lactation, parity, breed and milk yield with the filling effect of the feed. Similarly the Wageningen-Dairy Cow Model (DCM) (Zom et al. 2012a, 2012b) works, but without considering milk yield and live weight for feed intake capacity. The TDMI-Index (total dry matter intake) system (Huhtanen et al. 2011) combines the silage-DMI (SDMI)-Index and the concentrate-DMI (CDMI)-Index. While the SDMI-Index pictures the forage quality including parameters like digestibility and fermentation quality, the CDMI-Index considers amount and composition of concentrate.

Model no. 5 for TMR (Gruber et al. 2004) includes concentrate proportion of mixed ration instead of amount like in equation no. 1 for separate concentrate supplementation. Although Jensen et al. (2015) found the model no. 5 for TMR (Gruber et al. 2004) to be the most accurate one compared with the before mentioned up-to-date models, it was not chosen for estimating TMR in this project. Instead model no. 1 for separated concentrate supplementation was applied, and modified for PMR and TMR. Because a specific prediction model for PMR of Gruber et al. (2004) does not exist, model no. 1 had to be adapted to it anyway. A PMR is a more general type of a TMR, because of the additional separately fed concentrate. Furthermore using the same equation only with adaptations to the feeding system guarantees a uniform estimation of feed intake.

Another advantage of the models by Gruber et al. (2004) is the special consideration of the influence of stage of lactation on the regression coefficients for live weight, milk yield and concentrate level. Therefore they vary with day in milk. Thus, the changes of physiological stage from early to late lactation are taken in account, i.e., the change from a catabolic to an anabolic metabolism (Korver 1982). Forage substitution by concentrate is higher at the end of lactation, and the influence of live weight decreases due to gained body fat (Gruber et al. 2004).

2.1.5 Conclusions

The recording of novel phenotypes from about 5,300 cows on 167 farms, especially of feeding information per individual, was a big challenge. The feeding data base had to be designed using the experiences with the survey forms of the first half year of data collection. Without this experience revealing the diversity of feeding systems of the 167 farms, ration compositions and the way to describe this could not have been considered for data entering and feed intake estimation.

Rations had to be partitioned into mixed, fixed and ad lib components, which reflect the way the feed was offered like fixed concentrate with automation or manually, mixed concentrate together with mixed forage components in a TMR or PMR. Ad lib components had to be inserted into the data encoding system, because mostly the amount or proportion of pasture was not known.

This system of encoding ration components was the only possibility, to make the variety of diets and feeding systems handy for feed intake estimation. The estimation model had to be adapted to the 16 cases of feeding systems, which results from the 16 possible combinations of different categories of component

Without this novel system of handling the on-farm information, the estimation of feed intake and calculation of mostly individual nutrient contents in finally individual total rations would not have been possible with data observed on-farm.

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2.2 Analysis of lactating cows in commercial Austrian dairy farms: Diet composition, and influence of genotype, parity and stage of lactation on nutrient intake, body weight and body condition score

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Analysis of lactating cows in commercial Austrian dairy farms: Diet composition, and influence of genotype, parity and stage of lactation on nutrient intake, body weight and body condition score

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2.2.1 Abstract

This study characterises diets used on-farm and examines nutrient and feed intake (DMI) together with other animal specific traits (body weight, milk yield, body condition score). Data came from the project ‘Efficient Cow’ to develop efficiency traits for Austrian cattle breeding (161 farms, 6105 cows, one-year data collection). Most diets were grass silage- or maize silage-based. Nearly half (42.8%) of the records were diets with separately fed concentrate or were partial mixed rations (PMR, 42.9%), and 12.0% were total mixed rations (TMR). Feedstuffs from permanent grassland ranged between 62% (TMR) and 84% (pure forage diets) of forage. Partial mixed rations and TMR showed the highest average proportion of maize silage (30%). The little importance of pure forage diets and pasture reflected the above-average production level of the farms. Most production traits increased from Fleckvieh (FV) over FV groups with increasing Red Holstein (RH) genes to Holstein Friesian (HF). The FV group with highest RH proportion and HF had the highest energy corrected milk yield (ECM) and DMI (29.3 vs. 29.2 kg ECM/d; 20.8 vs. 20.9 kg DMI/d). Brown Swiss (BS) and FV had lower levels (26.5 vs. 26.7 kg ECM/d; 19.8 vs. 19.7 kg DMI/d). Body condition declined in relation to proportion of RH genes from FV to HF (FV 3.42 Pt., BS 2.88 Pt., HF 2.61 Pt.). The study allowed a broad view on the continuous spectrum between dual-purpose and dairy breeds due to the different characteristics of metabolism and on the common diets on Austrian dairy farms.

KEYWORDS: diet composition; feed intake; body condition score; lactation stage

2.2.2 Introduction

In Austria 47.5% of the agricultural area was permanent grassland in 2013, of which 56.5% was extensively used e.g. alpine pastures (BMLFUW 2016). In 2015, dairy production contributed to the total Austrian agricultural production value with 16.5%. Therefore, it plays a major role in producing products for human consumption from fibrous matter (BMLFUW 2016). In Austria, the following dairy breed distribution exists: Fleckvieh (FV, dual-purpose Simmental) is the dominant breed at 73.3% of all 422,777 recorded dairy cows, followed by the specialised dairy breeds Brown Swiss (BS) at 12.0% and Holstein Friesian (HF) at 11.7%. Compared to 1950, in 2015 milk yield per lactation has more than doubled (2998 kg vs. 7281 kg, ZAR 2016). The sharp increase

since 1995 has been caused by pronounced genetic gain and by dropping prices of concentrate with Austria's accession to the European Union (Knaus 2009; ZuchtData 2016). This change of circumstances resulted in an increase of larger, more specialised farms feeding more intensive diets (Knaus 2016). However, feed costs make up approximately 50% of the total costs in dairy production (de Haas et al. 2014). Besides environmental impacts, feed costs are one reason why international research in dairy cattle focuses on efficiency or efficiency related traits like body weight, feed and energy intake, body condition score (BCS) or reproduction (e.g. Veerkamp 1998; Pryce et al. 2000). Several comparisons among breeds or cows with different potential for milk performance were conducted (e.g. Dillon et al. 2003; Yan et al. 2006).

The Federal Association of Austrian Cattle Breeders (ZAR) initiated the project 'Efficient Cow' in 2012 to compare different dairy cow genotypes relating to efficiency traits, and the impact of higher efficiency on greenhouse gas emissions. As recording efficiency related traits in research herds is limited in Austria, the project focused on a large-scale on-farm data collection. This offered the possibility to additionally study feeding and diet plans, production and management of the commercial Austrian dairy farms. Furthermore veterinarian diagnoses, lameness scores, ketosis milk tests and hoof trimming data were recorded for testing novel health traits. The aim of this paper is twofold: firstly, the paper describes diet composition according to feeding system and primary forage components (forage type). Secondly, it discusses the influence of genotype, parity and lactation stage on feed and nutrient intake, milk yield, body weight and BCS. Furthermore, the effect of genotype considers the impact of the 'Holsteinization' (Harris and Kolver 2001, p. E56) of Austrian FV by creating FV groups with increasing Red Holstein (RH) genes.

2.2.3 Materials and methods

2.2.3.1 Data recording and calculation

No work carried out for this research was subject to the approval of an ethics committee. Data was collected in 2014 from 161 dairy herds and 3634 FV, 1034 HF and 1437 BS cows. Austria is partitioned into eight main production areas due to topography and climate (Statistik Austria 2018). All farms were located in the traditional dairying regions. They were situated between 300 and 1460 m above sea level in flat, hilly and mountainous areas. Genotypes were spread over all production areas picturing Austrian distribution of breeds (ZAR 2016). The number of single-breed farms owning BS was 24, HF 8, and FV 78. Within all single-FV farms pure-bred FV was also mixed with FV×RH. In the remaining farms, two (39 farms) or three breeds (12 farms) were kept. The number of animals per breed within these multi-breed farms is quite heterogeneous. Single cows of other breeds or crosses with other breeds (except FV×RH crosses) were not considered in this study. Most of the cows were housed in free-stall barns and milked twice a day in a milking parlour. At each routine performance recording day, the Austrian milk recording organisations collected additional trait information like body weight (with a mobile scale), BCS, belly girth, heart girth, diet, and diet quality. Forage was sampled at the start of project, or before forage was fed during year. Forage samples were taken separately based on botanic origin, number of growth (first cutting separately) and conservation. Data was recorded into the Austrian central cattle database following extensive plausibility checks. The milk recording methods AT4 and AT5 with annual 9 to 11 alternated one-test recordings were usually applied (ICAR 2017). On average, farms had 9.8 performance recordings. The number of reports per cow ranged between 1 and 12 with a mean of 6.2 reports and a mode of 8. Herd sizes ranged be-

tween 3.2 and 97.9 cows reflecting the wide range of herd size in Austria. The average herd size of 32.7 cows was almost twice as high as the Austrian average of 16.5 cows (ZAR 2016). Compared to other Austrian farms, the project farms had an above-average production level. A more specialised dairy production with larger herds replaced small-scale operations during the last 50 years (Knaus 2009, 2016). This trend is continuing (BMLFUW 2016).

Forage samples were analysed in the laboratory for feed analyses of the Chamber of Agriculture in Lower Austria. Forage samples were analysed for crude protein, ether extracts, crude fibre, ash, and dry matter according to Weende analysis. Neutral detergent fibre, acid detergent fibre and acid detergent lignin were quantified according to Van Soest et al. (1991). Methods were applied according to the guidelines by VDLUFA (1976–2012). On average 7.5 forage analyses were available per farm. Chemical composition of concentrates was obtained from DLG (1997) supplemented by LfL Grub (2015). Ingredients of commercial compound feed were provided by Tiefenthaller (2014). Energy content and utilisable crude protein at the duodenum (uCP) were calculated according to GfE (2001), the interpolation of digestibility coefficients and proportion of uCP (DLG 1997) were performed according to Gruber et al. (1997). The average chemical composition of feedstuffs is presented in Table 1A. Because only individual concentrate intake could be measured on-farm, novel strategies for recording information on diet composition and estimating individual feed intake were developed considering the wide variety of diet composition and feeding systems in Austria (Ledinek et al. 2016). The feeding systems are pure forage diets (FOR), diets with separately fed concentrate (e.g. feeding station, SEP), both partially mixed and separately fed concentrate (e.g. mixing wagon plus feeding station, PMR) and total mixed rations (TMR). Information on diet composition was collected by means of forms at each test day (Ledinek et al. 2016). Before data entry, completed forms were checked across dates and different form types within each farm to ensure a complete data recording. Implausibilities were clarified with the person responsible for on-farm data recording or with the farmer. The most important feeding data is:

- Start date of fed concentrate mixture and ration
- Feeding system: TMR, PMR and SEP (FOR = SEP without concentrate)
- Category of forage considering conservation (fresh, silage, hay), number of growth and botanical origin (grassland, forage maize, legumes, straw)
- Concentrate mixture and commercial compound feed
- Individual amount of concentrates fed separately from forage

Daily dry matter intake (DMI) was predicted using the feed intake model developed by Gruber et al. (2004). Jensen et al. (2015) validated the up-to-date feed intake models of NRC (2001), Volden et al. (2011), Wageningen-DCM (Zom et al. 2012), TDMI-Index (Huhtanen et al. 2011) and Gruber et al. (2004). The model of Gruber et al. (2004) was found to be the most accurate in this evaluation. The validation was based on a set of 12 Scandinavian experiments involving 917 lactating dairy cows and 94 treatments. The breeds were Jersey and Danish/Swedish Red, varying in parity and lactation stages. Prediction models considered similar feed- and animal-specific parameters. The empirical regression model of Gruber et al. (2004) includes the fixed effects of breed, parity, management level, lactation stage depending on days in milk (DIM), and the regression coefficient for the energy content of forage. The regression coefficients for milk per-

formance, body weight and amount of concentrate have to be calculated depending on DIM. Collection of information on diet composition and feed intake prediction were described in detail by Ledinek et al. (2016).

Energy corrected milk yield (ECM) was calculated according to the guidelines of GfE (2001). Daily net energy intake and nutrient intake were determined by multiplying net energy and nutrient density with the estimated daily dry matter intake. BCS recording followed the five-point system of Edmonson et al. (1989).

2.2.3.2 Statistical analysis

The data set included 38,070 milk recording results from 6105 cows on 161 farms. Data had been statistically and visually checked using Statgraphics Centurion XVII (2015 Statpoint Technologies, Inc., Warrenton, Virginia, USA), MS Excel 2010 and MS Access 2010 before and during processing (e.g. feed intake prediction). Depending on traits and their distribution, records were discarded if they deviated with standard deviation ≥ 3 (e.g. body weight, belly and heart girth) or ≥ 3.5 (e.g. BCS and muscle score) from the previous or the next record of a cow without plausible reason. Cows with conspicuous records were additionally checked across all traits. Before final statistical modelling in SAS, the used data and their distributions were checked to identify effects for modelling. In this process, records with DIM > 336 (lactation stage > 12) were discarded due to a low number of records.

Another point was to identify the primary forage components within diets for establishing forage types. This classification was used for analysing diet composition and for keeping the effect of forage constant within the statistical model. The starting point was the individual forage composition at each performance recording (38,070 records). Diets, which consisted of an above-average proportion of a forage component (e.g. GS: grass silage; MS: maize silage) were encoded as 'based on the respective forage'. Then respective codes from each record were combined (e.g. GSMS) and resulted in the presented forage types (Figure 1A.a). Finally, the proportion of each forage component was analysed within forage type (as done within feeding system Figure 1A.b). Tables 2A and 3A show the distribution of records, farms and cows within forage type and feeding system. The higher number of cows and farms is due to double counting. Farmers could change the way and amount of concentrate feeding and therefore the feeding system as well as the fed forage. This could happen either for the entire herd or an individual cow depending on milk performance or available feedstuff. Therefore, all statistical (descriptive) analyses refer to the individual feeding situation rather than farm or herd level.

The classes HF and BS included pure-bred cows only (100% HF and BS ancestry). Fleckvieh cows were classified into FV (100% FV, 1576 cows), FV×RH6.25 (FV with $\leq 10\%$ RH genes, average of 6.25%, 963 cows), FV×RH12.5 (FV with > 10 to $\leq 15.6\%$ RH genes, average of 12.5%, 342 cows), FV×RH25 (FV with > 15.6 to $\leq 44.5\%$ RH genes, average of 25%, 404 cows), and FV×RH5075 (FV with $> 44.5\%$ RH genes, average 68%, 349 cows, the groups FV×RH50 and FV×RH75 were combined). The proportion of RH genes in the dual-purpose breed Fleckvieh was chosen to characterise specialisation on dairy performance (potential for milk production). This system allowed an objective comparison between dual-purpose type FV and the specialised dairy type HF/RH. Contrary to this, a comparison using estimated breeding values is only valid within population. Genotypes were distributed over all feeding systems (Table 4A) and forage types. The proportion of FV data in feeding systems decreased from FOR, SEP, PMR to TMR with 41.2 to 18.7%. The

group HF had the highest proportion in PMR and TMR (20.7 and 20.6%). With both about 28% of all data records BS had an emphasis on SEP and TMR.

Days in milk were divided into 28-day classes (4×7 days, lactation months) of lactation stage. The final model included twelve classes with DIM 1 to 336.

Data was analysed using PROC MIXED (SAS 9.4, SAS 2015), REML for the estimation of variance components, the Kenward-Roger method for the approximation of the denominator degrees of freedom and the default covariance structure VC. This covariance structure models a different variance component for each random effect and had the smallest Akaike information criterion. The fixed effects of genotype, parity (1, 2, 3+4, ≥ 5), lactation stage (1–12) and their interactions as well as forage type (1–18, Figure 1A.a,b) and farm (1–161) were included in the final model. Thus, influence of diet and management was considered. The model also included a random cow effect (1–6105) nested within genotype and farm. The effect of forage type on DMI, nutrient intake and the other traits is not discussed in this publication, because it was only included as correction factor and is not the topic of discussion in this article. Multiple comparisons were carried out using the specification ADJUST = TUKEY and the differences between the least squares means within genotype and parity with $p < 0.05$ were considered significant.

2.2.4 Results and discussion

2.2.4.1 Descriptive statistics of diet composition and feeding system

Figure 1A.a illustrates forage composition according to forage type. The groups of bars show diets containing above-average fresh grass (pasture), grass silage, maize silage, clover, alfalfa and hay from permanent grassland. Preservation and botanical composition varied considerably due to climatic variation in Austria. However, forage composition is split into two primary categories: nearly pure grass silage ration [type GS (grass silage) 82% grass silage, 39.5% of data records] and type MS (maize silage) with 49% maize silage and 42% grass silage (27.1% of data records). Type MS equated approximately to the diets of commercial Danish herds (Kristensen et al. 2015). Although milk production based on alfalfa and clover represented only 8.5 and 2.6% of data records, growing legumes was regionally able to replace forage from permanent grassland. In contrast grass silage from Danish farms is rye grass- and clover-based (Kristensen et al. 2015). Only 8.1% of records belonged to hay-based diets (56.5% hay). The rare use of pasture-based diets (5.6% of data records) has two reasons: on one hand, pasture is more limited by climate and topography than e.g. in Ireland and New Zealand, where seasonal grazing systems are common (Dillon et al. 1995; Harris and Kolver 2001). On the other hand, the project farms represented an above-average production level in Austria.

Figure 1A.b describes forage composition according to feeding system. Concentrate was either mixed (totally) into forage in PMR and TMR or supplemented separately via feeding station (SEP). Pure forage diets contained a high proportion of pasture and hay. Pasture and hay were hardly common in the more intense PMR and TMR. The proportion of grass silage, especially of maize silage, increased simultaneously to nearly 60 and 30% of forage dry matter in the mixed rations. Despite this, feedstuffs from permanent grassland dominated with at least 62% of forage in TMR and most at 84% in FOR. Concentrate proportions of SEP, PMR and TMR were 27, 35 and 30%. Pure forage diets were used only at 2.4% of milk performance tests. Partially separate and individual concentrate supplementation dominated with 85.7% (42.8% SEP, 42.9% PMR).

Overall, concentrate levels, the degree of mechanisation (data not shown) and the lack of pasture as well as pure forage diets confirmed that project farms rank at the current upper end of the structural change of Alpine dairy farming. Larger, non-seasonal, indoor-feeding and more specialised dairy production more and more replaced the traditional, forage-based and small-scaled one in the last 50 years (Knaus 2009, 2016).

2.2.4.2 Effect of genotype

Estimated feed and nutrient intake as well as total diet composition differed among genotypes ($p < 0.001$). Especially FV groups up to an average of 12.5% RH genes were biologically similar (Table 5A). Differences increased with a higher RH gene proportion. The groups HF and FV×RH5075 were similar in most traits except parameters calculated relative to body weight. The dairy type BS was mainly located in the range of FV to FV×RH25 for nutrient and dry matter intake, but was similar to HF and FV×RH5075 relative to body weight. This was expected after examination of previous results from Ledinek and Gruber (2014) and data from Austrian dairy cow performance recording program (ZAR 2016).

Relative to body weight, differences in DMI and neutral detergent fibre (NDF) intake between the lighter specialised dairy groups and the heavier FV groups were emphasised. Dillon et al. (2003) found a higher decline of relative DMI from Danish HF and Irish HF to the lower yielding breeds French Montbeliarde and Normande. This effect occurred between cows of medium and high genetic merit for dairy traits within the same breed as well (Kennedy et al. 2003). Furthermore, increased concentrate supplementation enhanced the DMI of HF cows kept on pasture. The higher feed intake and concentrate proportion in cows and breeds of higher milk yield potential were also found in the studies of e.g. Gruber et al. (1995) and Dillon et al. (2003). Overall, the level of g NDF per kg body weight indicates DMI was not physically limited by fibre content in the diet. However, with 12.2 g NDF/kg body weight HF approaches the limit of 12.5 g NDF/kg body weight described by Mertens (1994). Therefore, fibre content was high relative to energy requirements, although concentrate proportion and diet quality were the highest of all genotypes. Total diets used in the commercial Danish dairy farms (Kristensen et al. 2015) are characterised by a slightly higher crude protein but slightly lower NDF content. This is most likely due to higher maize silage proportions (nearly 50%) and the rye grass-clover mixture of grass silage. The lower intake of uCP rather than crude protein in the current study indicated a small surplus of rumen degradable nitrogen. This surplus was below the tolerable 50 g/d (GfE 2001).

Intake parameters and ECM increased in relation to potential of milk performance. In contrast, average body weight, even more clearly BCS, declined in accordance to the findings by Dillon et al. (2003). Apart from body weight, similar results were found for medium and high genetic merit HF cows (Buckley et al. 2000). We recorded the highest body weight difference between the two poles, with HF and BS having the lowest (662 and 649 kg). The FV groups up to an average of 25% RH genes had the highest body weight (722 to 729 kg). In contrast, the BCS of BS having the same ECM as FV was approximately midway of HF and FV. Previous and comparable studies in Austria indicate a body weight range of 646 to 761 kg for FV, 589 to 688 kg for HF and 636 to 698 kg for BS (Gruber et al. 1995; Haiger and Knaus 2010; Ledinek and Gruber 2015; Gruber and Stegellner 2015). In a Swiss study by Piccand et al. (2013) BS, HF and FV were lighter and differences between FV and HF were smaller. However, cows were managed in a seasonal-calving, pasture-based dairy system and FV had a high proportion of RH equal to FV×RH5075.

In the current study, FV and BS produced 12% more milk than the average Austrian performance-tested cows of the relevant breeds in 2015. The group HF produced only 5% more (ZAR 2016). Therefore, FV and BS had more similarities to HF compared to their breed averages. This pictured the above-average production level of the project farms and the change in Austrian dairy production towards a more specialised and intensive one (Knaus 2009, 2016).

2.2.4.3 Effect of parity and genotype $\times$ parity

Parities differed in intake parameters, body weight and BCS ($p < 0.001$), but not in chemical diet composition (Table 5A). Although differences in concentrate proportion and energy content of the total diet were statistically significant, they were too small to be of biological significance. Interaction between genotype and parity is significant for most parameters except diet quality (data not shown). However, the order of genotypes within parity mostly remains the same. In cases when it did not, differences were numerically small and not significant.

The effect of parity pictured the growth and aging of the cows within all genotypes. Estimated intake of concentrates, forage, crude protein, uCP, energy and DMI developed in a degressive and simultaneous increase up to parity 3+4. A slight decline to parity ≥ 5 followed. Contrary to ECM and the intake parameters, body weight increased to parity ≥ 5 , and BCS decreased.

Cows of parity 3+4 had a 2.78 kg higher DMI than cows of first parity, the concentrate being 0.99 kg. Kennedy et al. (2003) reported an increase of 4.4 kg to the third parity, whereas Buckley et al. (2000) observed only an increase up to second parity. Relative to body weight we found that cows of parity 3+4 only had a higher DMI of 7.4 g DM compared to first parity cows. Relative feed intake was slightly lower than in parity 2, although cows of parity 3+4 had a higher milk performance. Additional requirements for higher milk yield were not completely met in parity 3+4 as the development of BCS showed, although milk performance is an important driver of DMI (Kennedy et al. 2003; Gruber et al. 2004). Due to the similar proportion of concentrate among all parities within genotype, the positive effect of higher levels of concentrate on DMI (Kennedy et al. 2003) is negligible. The lower DMI per kg body weight of cows in parity ≥ 5 can be explained with higher body weight and lower requirements for milk performance. Furthermore, more frequent diseases in older cows reduce DMI as shown in several studies on feed intake (Gruber et al. 2004).

Daily ECM increased up to parity 3+4 with 29.3 kg, with the biggest rise between parity 1 and 2. This agrees with Kennedy et al. (2003) and Gruber and Stegellner (2015). In the current study HF had the highest increase from parity 1 to 3+4 with 5.8 kg ECM, followed by BS with 5.1 kg. The peak in milk performance of FV $\times$ RH6.25 and FV $\times$ RH12.5 was less pronounced in parity 3+4 than in the other groups.

Body weight grew degressively as reported in diverse studies (Enevoldsen and Kristensen 1997; Buckley et al. 2000; Yan et al. 2006). In parity ≥ 5 cows were 100 kg heavier than in the first parity with 644 kg. The specialised dairy groups BS and HF had a similar body weight in parity 1 with 600 and 606 kg, but growth was less pronounced in BS (75 vs. 93 kg difference). All FV groups gained more than 100 kg and had up to 772 kg in parity ≥ 5 . This big difference between young and older cows was not found to be unusual. Blöttner et al. (2011) reported differences of 88 and 100 kg for HF $\times$ BS and HF between parity 1 and 3. Buckley et al. (2000) observed 99 kg. Comparable Austrian studies described a body weight of 640 to 654 kg for first parity cows and 740

to 757 kg for cows in the last parity classes (Ledinek and Gruber 2014; Gruber and Stegellner 2015).

2.2.4.4 Effect of lactation stage and genotype $\times$ lactation stage

Feed intake parameters, total diet nutrient content, milk production, BCS, and body weight varied across stages of lactation ($p < 0.001$; Table 6A). The interaction between genotype and stage of lactation was significant and is shown in Figure 2A. It does not include the groups FV $\times$ RH6.25 and FV $\times$ RH12.5, which are similar to FV, to increase readability of the figure.

Highest estimated DMI (21.49 kg DM/d; 161.8 g/kg BW^{0.75}) and nutrient intake were reached at lactation day 71 together with highest quality of total diet and highest concentrate proportion of 33.1%. Daily ECM peaked earlier on day 43 with 33.5 kg/d. Forage intake increased until the end of lactation up to 14.99 kg DM/d. Despite higher NDF content in the total diet NDF intake per kilogram of body weight was lower. This was due to increasing body weight and decreasing milk performance (Figure 2A). Feed intake of low yielding cows was limited by energy requirements (Mertens 1994). Milk yield and concentrate levels had been identified as important drivers of DMI before (Gruber et al. 1995; Kennedy et al. 2003). Yet, the lactation stage effects are based on the maintenance of the physiological state of milk production by homeorhesis (Bauman and Currie 1980). Hormones like growth hormone, insulin or insulin like growth factor and the sensitivity of body tissue regulate the partitioning of nutrients between body tissue and milk production (Hart 1983; Vernon and Sasaki 1991). Furthermore, the change from reproduction to lactation leads to the observed low DMI close to calving (Ingvarsen and Andersen 2000). Therefore, milk is produced (nearly) independently from feed intake in early lactation. This is only possible via genetically driven body energy change (Friggens et al. 2007), insulin resistance, and the uncoupling of the somatotrophic axis especially in high yielding cows (Lucy et al. 2009). Body weight and BCS mirror the milk performance curve and show mobilisation and regaining of body reserves for milk production.

Focusing on the interaction between genotype and lactation stage (Figure 2A), we found that HF with the highest DMI reached its peak intake later at lactation day 99, while having a nearly constant high concentrate level. In later lactation concentrate supplementations of FV $\times$ RH5075, especially of HF, remained at higher levels in contrast to other genotypes. Daily ECM decreased more than that of the FV groups up to an average of 25% RH genes. In a study by Yan et al. (2006), HF cows produced more milk at a constant concentrate level than Norwegian cows. However, HF cows fed high concentrate diet partitioned a higher proportion of the additional energy intake to milk energy, particularly in early lactation, compared to those fed low concentrate diet. But this superiority drastically declined in late lactation. This corresponded with the decrease of growth hormone and non-esterified fatty acids as well as a significant increase of blood glucoses of high producing cows between lactation and dry period (Hart et al. 1979). In the current study, BCS loss of HF was highest of all groups. Body condition stagnated at its lowest level until DIM 154, but was regained faster. This led to the same BCS like shortly after calving on DIM 17. Contrary to this, the FV groups lost less body reserves and regenerated earlier. Finally, they had a higher body condition in late lactation than did DIM 17. Cows with high genetic merit in milk production had a higher loss but a faster regeneration of body reserves especially in dry period (Buckley et al. 2000). Similarly, differences between breeds are based on nutrient partitioning between milk production and body reserves as reported in several studies (Dillon et al.

2003; Yan et al. 2006). The specialised dairy type HF used high quality diet in late lactation for regaining depleted body store.

2.2.5 Conclusions

Diet composition showed Austria's division into agriculturally favourable (maize silage-based) and mountainous regions (permanent grassland-based). Concentrates were fed mostly via feeding station and adapted to individual requirements. Pure forage diets and pasture were used rarely. This confirmed that the project farms belong to the current above-average production level in Austria following the trend of Austrian dairy farms towards intensification.

Daily DMI and ECM increased in relation to RH gene proportion in FV, but were based on higher diet quality and concentrate intake as well as on a more intensive BCS loss and later regeneration during lactation. Average BCS and body weight decreased with higher RH proportion, but 68% RH genes were necessary to affect body weight toward HF. Although BS is mainly bred for dairy performance, potential for milk production seemed to be low to medium. Daily ECM and DMI were similar to the FV groups up to an average of 12.5% RH genes. In conclusion, the study conducted created an expanded view of the continuous spectrum between dual-purpose and dairy breeds regarding varying metabolism characteristics.

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Table 1A. Chemical composition ($\pm$ standard deviation) of selected forages in g/kg dry matter (DM), unless stated otherwise.

Parameter	Fresh grass	Grass silage	Hay	Maize silage	Clover [*]	Alfalfa [*]	Whole crop cereals
DM, g of fresh matter	188 $\pm$ 22.6	356 $\pm$ 68.9	926 $\pm$ 20.6	337 $\pm$ 40.8	381 $\pm$ 134.4	734 $\pm$ 256.9	195 $\pm$ 35.2
Crude protein	176 $\pm$ 24.1	153 $\pm$ 20.3	105 $\pm$ 20.3	73 $\pm$ 9.6	159 $\pm$ 24.4	159 $\pm$ 19.6	118 $\pm$ 16.2
uCP [¶]	142 $\pm$ 5.7	132 $\pm$ 5.7	120 $\pm$ 7.7	130 $\pm$ 3.0	139 $\pm$ 6.9	127 $\pm$ 6.1	128 $\pm$ 6.9
NDF [†]	422 $\pm$ 28.3	438 $\pm$ 41.7	536 $\pm$ 55.5	384 $\pm$ 34.3	440 $\pm$ 50.7	455 $\pm$ 42.8	476 $\pm$ 76.5
ADF [‡]	271 $\pm$ 21.0	313 $\pm$ 30.2	352 $\pm$ 36.3	226 $\pm$ 26.0	331 $\pm$ 42.8	355 $\pm$ 38.1	316 $\pm$ 56.4
ADL [#]	42 $\pm$ 7.3	51 $\pm$ 11.6	63 $\pm$ 12.2	32 $\pm$ 5.8	60 $\pm$ 13.0	75 $\pm$ 15.6	38 $\pm$ 8.6
NFC [§]	283 $\pm$ 34.6	268 $\pm$ 34.8	251 $\pm$ 39.8	476 $\pm$ 42.1	269 $\pm$ 35.5	261 $\pm$ 34.0	272 $\pm$ 73.3
ME [§] , MJ/kg DM	10.66 $\pm$ 0.41	9.94 $\pm$ 0.38	9.30 $\pm$ 0.50	10.87 $\pm$ 0.25	10.37 $\pm$ 0.49	8.76 $\pm$ 0.56	10.07 $\pm$ 0.45
NEL ^{&} , MJ/kg DM	6.43 $\pm$ 0.30	5.93 $\pm$ 0.26	5.45 $\pm$ 0.35	6.56 $\pm$ 0.19	6.24 $\pm$ 0.36	5.07 $\pm$ 0.39	6.01 $\pm$ 0.33

^{*}hay and silage; [¶]uCP: utilisable crude protein at the duodenum [GfE 2001]; [†]NDF: neutral detergent fibre; [‡]ADF: acid detergent fibre; [#]ADL: acid detergent lignin; [§]NFC: non-fibre carbohydrates; [§]ME: metabolisable energy; [&]NEL: net energy for lactation

Table 2A. Distribution of records, cows and farms in forage types.

Forage type	Records (N = 38,070)	Subcategories (N = 18)	Records (N = 38,070)	Cows [*] (N = 11,810)	Farms [¶] (N = 403)
Fresh grass (FG)	2136	FG	1198	534	30
		FGHA	697	321	20
		FGGSHA	241	149	9
Grass silage (GS)	17,662	GS	15,054	3622	102
		GSHA	1267	696	34
		GSMS	313	224	7
		GSMSHA	1028	769	27
Maize silage (MS)	10,826	MS	10,325	2487	59
		MSHA	202	131	6
		MSGST [†]	163	89	3
		MSGSFG	136	68	3
Clover (CL)	3250	CLGMSHA	2821	912	23
		CLMS	429	235	8
Alfalfa (AL)	985	ALGSHAMS	650	224	10
		ALMS	162	51	2
		ALGS	173	124	3
Hay (HA)	3089	HA	3089	1068	52
OTHER	122	OTHER	122	106	5

^{*}total number of cows 6105, but double counting due to changing diet

[¶]total number of farms 161, but double counting due to changing diet; [†]ST: straw

Table 3A. Distribution of records, cows and farms in feeding systems.

Feeding system [*]	Records (N = 38,070)	Cows [¶] (N = 8169)	Farms [†] (N = 313)
FOR	913	529	72
SEP	16,283	2982	106
PMR	16,334	3255	72
TMR	4540	1403	63

^{*}FOR: pure forage diet; SEP: forage diet with separately fed concentrate; PMR: partial mixed ration; TMR: total mixed ration

[¶]total number of cows 6105, but double counting due to changing diet

[†]total number of farms 161, but double counting due to changing diet

Table 4A. Data distribution of genotypes in feeding systems.

Genotype [*]	Feeding system [¶]				N Genotype
	FOR	SEP	PMR	TMR	
FV	376	4597	4118	851	9942
FV×RH6.25	133	2702	2616	518	5969
FV×RH12.5	22	937	981	216	2156
FV×RH25	44	969	939	413	2365
FV×RH5075	18	826	1014	322	2180
HF	152	1704	3381	935	6172
BS	168	4548	3285	1285	9286
N Feeding system	913	16,283	16,334	4540	38,070

^{*}FV: Fleckvieh; RH: Red Holstein; 6.25 – 5075: average proportion of Red Holstein; FV×RH5075: Fleckvieh with an average proportion of 68% Red Holstein; HF: Holstein Friesian; BS: Brown Swiss

[¶]FOR: pure forage diet; SEP: forage diet with separately fed concentrate; PMR: partial mixed ration; TMR: total mixed ration

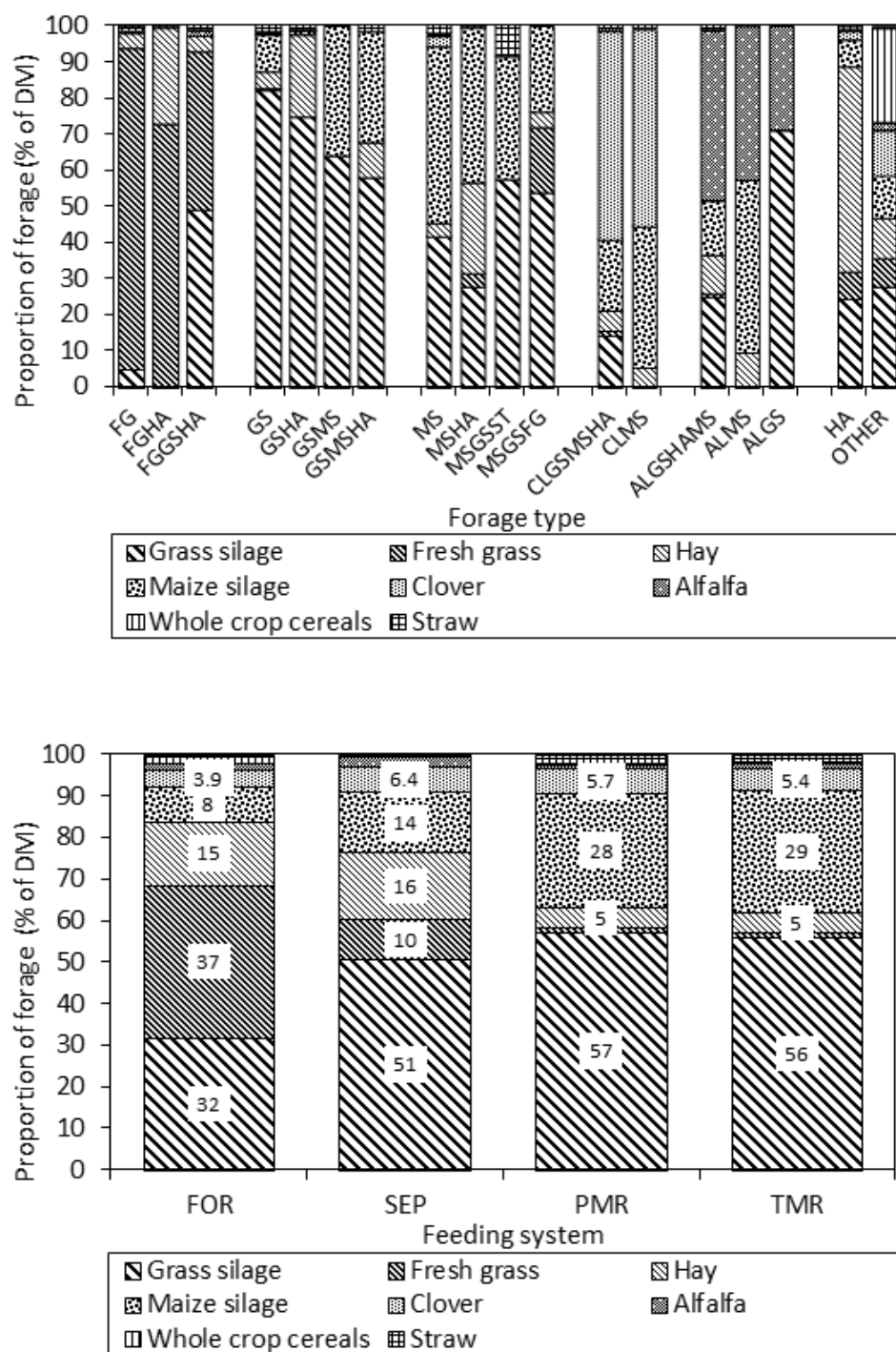


Figure 1A.a (upper). Forage composition according to forage type (FG: fresh grass; GS: grass silage; HA: hay from permanent grassland; MS: maize silage; CL: clover; AL: alfalfa; ST: straw). Forage type: Diets, which consisted of an above-average proportion of one of the above-named forage components, were encoded as 'based on the respective forage'. The respective codes from each record were combined and resulted in the presented forage types.

Figure 1A.b. Forage composition according to feeding system. The feeding system describes how diets and especially concentrates were fed (FOR: pure forage diet; SEP: forage diet with separately supplemented concentrate; PMR: partial mixed ration; TMR: total mixed ration). The grouping of feeding system and forage type is based on the individual diet composition at each performance recording (N = 38,070).

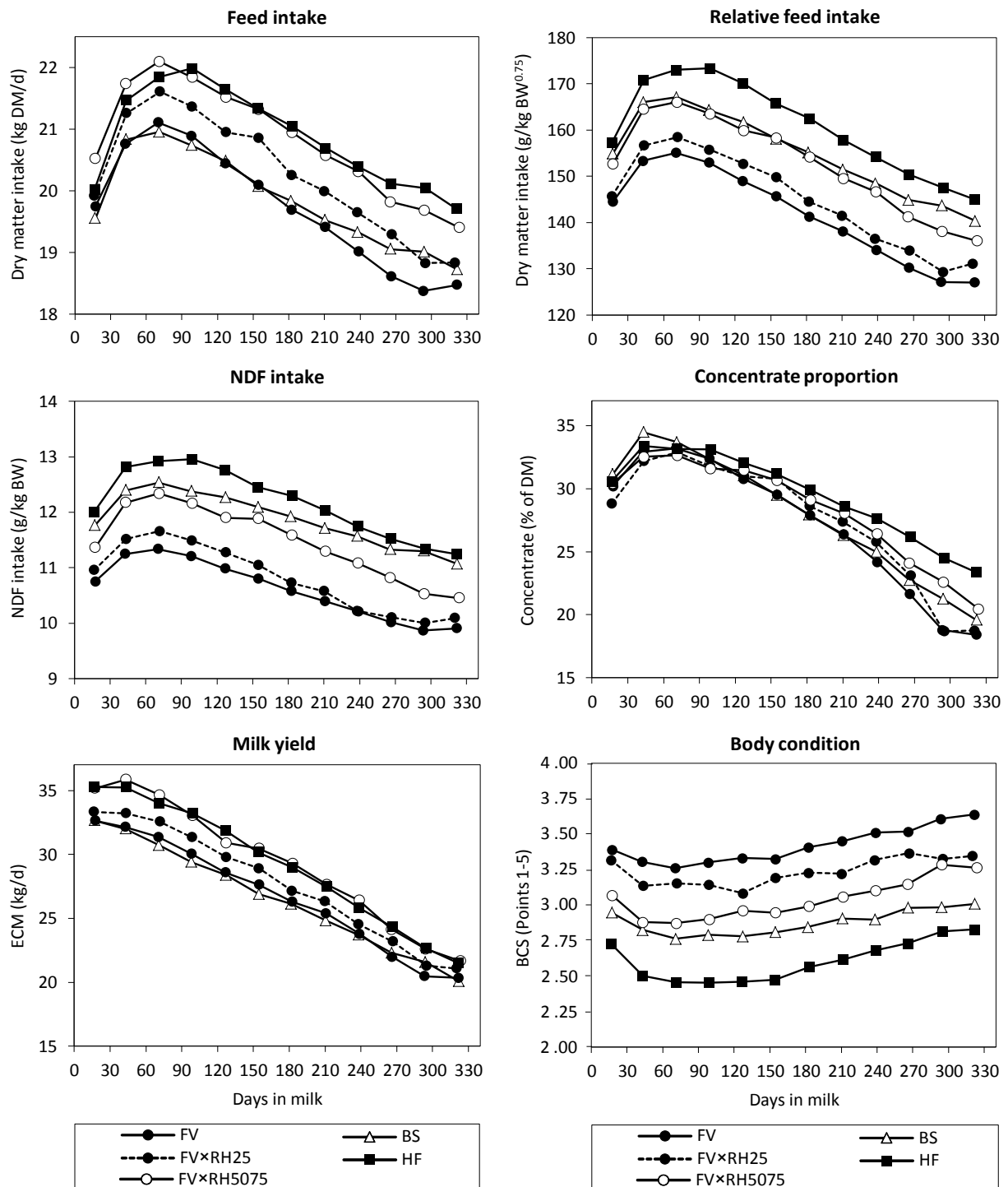


Figure 2A. Interaction between genotype and lactation stage for dry matter intake (DMI, $BW^{0.75}$: metabolic body weight), neutral detergent fibre (NDF) intake, concentrate proportion, energy corrected milk (ECM) and body condition score (BCS) of Brown Swiss (BS), Fleckvieh (FV), the selected FV groups with increasing Red Holstein (RH) genes FV×RH25 and FV×RH5075 as well as Holstein Friesian (HF).

Table 5A. Effect of genotype and parity on estimated daily feed and nutrient intake, chemical composition of diet and body weight, body condition score and milk yield (least squares means).

Trait	Genotype (G) [*]						Parity (P)					RMSE [¶]	p-value	
	FV	FV×RH6.25	FV×RH12.5	FV×RH25	FV×RH5075	HF	BS	1	2	3+4	≥5		G	P
Data set, N = 38,070	9942	5969	2156	2365	2180	6172	9286	10,856	8385	10,865	7964			
Feed intake														
Forage, kg DM/d	14.10 ^d	14.22 ^c	14.26 ^{bc}	14.40 ^b	14.63 ^a	14.41 ^b	13.96 ^d	13.01 ^c	14.54 ^b	14.81 ^a	14.77 ^a	1.15	< 0.001	< 0.001
Concentrate, kg DM/d	5.63 ^d	5.61 ^d	5.64 ^d	5.86 ^c	6.20 ^b	6.44 ^a	5.86 ^c	5.24 ^c	5.94 ^b	6.23 ^a	6.16 ^a	1.70	< 0.001	< 0.001
DMI [†] , kg DM/d	19.72 ^c	19.83 ^c	19.87 ^c	20.24 ^b	20.82 ^a	20.86 ^a	19.84 ^c	18.24 ^d	20.48 ^c	21.02 ^a	20.93 ^b	1.58	< 0.001	< 0.001
DMI [†] , g/kg BW ^{0.75}	141.5 ^d	141.6 ^d	142.0 ^d	144.7 ^c	152.6 ^b	160.7 ^a	154.7 ^b	143.4 ^d	151.5 ^a	150.8 ^b	147.4 ^c	11.6	< 0.001	< 0.001
Nutrient intake														
Crude protein, g/d	3065 ^c	3074 ^c	3076 ^c	3144 ^b	3241 ^a	3273 ^a	3101 ^{bc}	2830 ^c	3188 ^b	3278 ^a	3259 ^a	388	< 0.001	< 0.001
uCP [‡] , g/d	2878 ^c	2890 ^c	2898 ^c	2957 ^b	3049 ^a	3070 ^a	2907 ^{bc}	2662 ^d	2993 ^c	3080 ^a	3063 ^b	293	< 0.001	< 0.001
Energy intake, MJ NEL/d	129.1 ^c	129.7 ^c	130.0 ^c	132.6 ^b	136.7 ^a	137.4 ^a	130.3 ^{bc}	119.4 ^d	134.2 ^c	138.1 ^a	137.4 ^b	12.7	< 0.001	< 0.001
NDF [#] intake, g/kg BW	10.6 ^e	10.6 ^e	10.6 ^e	10.8 ^d	11.5 ^c	12.2 ^a	11.9 ^b	11.1 ^c	11.4 ^a	11.2 ^b	10.9 ^d	0.9	< 0.001	< 0.001
Chemical composition of diet														
Forage														
Crude protein, g/kg DM	132	132	132	132	131	131	132	131 ^b	132 ^a	131 ^{ab}	132 ^{ab}	12	0.917	0.042
Crude fibre, g/kg DM	248	248	248	248	248	248	248	248	248	248	248	15	0.809	0.795
NDF [#] , g/kg DM	446	445	446	445	446	447	446	446	446	446	446	24	0.682	0.960
NEL [§] , MJ/kg DM	6.00	6.00	5.99	6.00	6.00	5.99	6.00	5.99	6.00	6.00	6.00	0.16	0.725	0.472
Complete diet														
Concentrate, % of DM	27.2 ^c	26.9 ^c	26.9 ^c	27.5 ^{bc}	28.3 ^b	29.5 ^a	27.9 ^{bc}	27.6 ^{bc}	27.5 ^c	28.0 ^a	27.9 ^{ab}	7.0	< 0.001	< 0.001
Crude protein, g/kg DM	154 ^{bc}	154 ^c	154 ^{bc}	155 ^{bc}	155 ^{ab}	156 ^a	155 ^{abc}	155	155	155	155	12	< 0.001	0.374
Crude fibre, g/kg DM	202 ^a	202 ^a	202 ^a	201 ^{ab}	199 ^{bc}	198 ^c	200 ^{ab}	201 ^a	201 ^a	200 ^a	200 ^a	16	< 0.001	0.026
NDF [#] , g/kg DM	391 ^a	391 ^a	391 ^a	389 ^{ab}	388 ^{bc}	386 ^c	390 ^{ab}	390	390	389	389	23	< 0.001	0.141
NEL [§] , MJ/kg DM	6.51 ^c	6.51 ^c	6.51 ^c	6.52 ^{bc}	6.54 ^{ab}	6.56 ^a	6.53 ^{bc}	6.52 ^c	6.52 ^{bc}	6.54 ^a	6.53 ^{ab}	0.19	< 0.001	< 0.001
Body weight (BW), body condition (BCS) and milk yield														
BW, kg	722 ^b	729 ^a	728 ^{ab}	725 ^{ab}	706 ^c	662 ^d	649 ^e	644 ^d	698 ^c	727 ^b	744 ^a	57	< 0.001	< 0.001
BCS, Points 1-5	3.42 ^a	3.39 ^a	3.38 ^a	3.24 ^b	3.04 ^c	2.61 ^e	2.88 ^d	3.16 ^a	3.14 ^b	3.13 ^b	3.12 ^b	0.46	< 0.001	< 0.001
ECM [§] , kg/d	26.7 ^c	27.0 ^c	26.9 ^c	27.7 ^b	29.3 ^a	29.2 ^a	26.5 ^c	24.5 ^d	28.0 ^c	29.3 ^a	28.6 ^b	5.5	< 0.001	< 0.001

^{a-e}Least squares means within a row and a fixed effect with different superscripts differ ($p < 0.05$); ^{*}FV: Fleckvieh; RH: Red Holstein; 6.25 – 5075: average proportion of Red Holstein; FV×RH5075: Fleckvieh with an average proportion of 68% Red Holstein; HF: Holstein Friesian; BS: Brown Swiss; [¶]RMSE: root mean square error; [†]DMI: dry matter intake; DM: dry matter; BW: body weight; [‡]uCP: utilisable crude protein at the duodenum (GfE 2001); [#]NDF: neutral detergent fibre; [§]NEL: net energy for lactation; [§]ECM: energy corrected milk (GfE 2001)

Table 6A. Effect of stage of lactation on estimated daily feed and nutrient intake, chemical composition of diet and body weight, body condition score and milk yield (least squares means).

Trait	Stage of lactation (DIM [*])												p-value	
	1	2	3	3	4	5	6	7	8	9	10	11	DIM	G [¶] × DIM
DIM [*]	17	43	71	99	127	155	183	211	239	266	294	321		
Data set, N = 38,070	2970	3757	3663	3594	3570	3401	3460	3302	3274	3050	2479	1550		
Feed intake														
Forage, kg DM/d	13.68	13.92	14.09	14.16	14.11	14.15	14.20	14.24	14.37	14.59	14.89	14.99	< 0.001	< 0.001
Concentrate, kg DM/d	6.23	7.28	7.40	7.14	6.83	6.44	6.04	5.65	5.19	4.55	4.07	3.88	< 0.001	< 0.001
DMI [†] , kg DM/d	19.90	21.19	21.49	21.29	20.93	20.59	20.24	19.88	19.56	19.13	18.94	18.86	< 0.001	< 0.001
DMI [†] , g/kg BW ^{0.75}	149.2	160.3	161.8	159.6	156.4	152.8	148.9	145.0	141.0	136.9	133.9	133.2	< 0.001	< 0.001
Nutrient intake														
Crude protein, g/d	3112	3377	3426	3385	3317	3243	3158	3084	3009	2903	2842	2811	< 0.001	< 0.001
uCP [‡] , g/d	2926	3156	3205	3164	3103	3040	2971	2901	2835	2741	2688	2667	< 0.001	< 0.001
Energy intake, MJ NEL/d	131.4	141.2	143.3	141.5	138.8	136.0	133.1	130.0	127.2	123.2	121.0	120.2	< 0.001	< 0.001
NDF [#] intake, g/kg BW	11.2	11.8	11.9	11.8	11.6	11.4	11.2	11.0	10.7	10.5	10.4	10.4	< 0.001	< 0.001
Chemical composition of diet														
Forage														
Crude protein, g/kg DM	131	132	131	132	132	131	131	132	132	132	132	131	0.484	0.012
Crude fibre, g/kg DM	249	248	248	247	247	247	247	248	248	249	248	248	< 0.001	0.164
NDF [#] , g/kg DM	447	446	446	445	445	445	445	446	446	447	446	446	0.165	0.263
NEL [§] , MJ/kg DM	5.99	5.99	5.99	6.00	6.00	6.01	6.01	6.00	6.00	5.99	5.98	5.99	< 0.001	0.422
Complete diet														
Concentrate, % of DM	30.1	33.1	33.1	32.2	31.3	30.0	28.6	27.1	25.3	22.6	20.2	19.4	< 0.001	< 0.001
Crude protein, g/kg DM	156	159	159	158	158	157	155	154	153	151	149	148	< 0.001	< 0.001
Crude fibre, g/kg DM	197	191	191	193	194	196	199	201	205	210	214	215	< 0.001	< 0.001
NDF, g/kg DM	385	378	379	380	382	385	388	391	395	401	405	406	< 0.001	< 0.001
NEL [§] , MJ/kg DM	6.58	6.64	6.64	6.62	6.60	6.58	6.55	6.52	6.48	6.42	6.36	6.35	< 0.001	< 0.001
Body weight (BW), body condition (BCS) and milk yield														
BW, kg	682	673	677	682	686	692	700	710	721	729	742	742	< 0.001	0.003
BCS, Points 1-5	3.18	3.02	3.00	3.01	3.02	3.05	3.11	3.15	3.21	3.25	3.31	3.33	< 0.001	< 0.001
ECM [§] , kg/d	33.4	33.5	32.6	31.1	29.8	28.5	27.4	26.0	24.5	22.7	21.2	20.8	< 0.001	< 0.001

^{*}LS-means of day in milk of 28-day classes 1-12; [¶]genotype; [†]DMI: dry matter intake; DM: dry matter; BW: body weight; [‡]uCP: utilisable crude protein at the duodenum (GfE 2001); [#]NDF: neutral detergent fibre; [§]NEL: net energy for lactation; [§]ECM: energy corrected milk (GfE 2001)

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2.3 Analysis of lactating cows in commercial Austrian dairy farms: Interrelationships between different efficiency and production traits, body condition score and energy balance

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Analysis of lactating cows in commercial Austrian dairy farms: Inter-relationships between different efficiency and production traits, body condition score and energy balance

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2.3.1 Abstract

This study examines the relationship between efficiency, energy balance and related traits like milk yield, feed intake (DMI), body weight and body condition score (BCS). Data was derived in the project 'Efficient Cow' to develop efficiency traits for Austrian cattle breeding (6105 cows, 161 farms, one-year data collection). The following efficiency traits were considered: body weight efficiency as ratio between energy corrected milk (ECM) to metabolic body weight, feed efficiency (kg ECM per kg DMI) and energy efficiency expressed as ratio between energy in milk to energy intake. The higher the proportion of Red Holstein (RH) in Fleckvieh (FV), the more (efficiently) milk was produced, but also at the expenses of body fat reserves. The negative energy state of Holstein Friesian (HF) and the FV groups with highest RH proportion lasted approximately twice as long as of the least efficient Brown Swiss. All genotypes regained lost body tissue during whole lactation. The high yielding groups required a higher concentrate proportion in late lactation to regain body condition. In early lactation high efficiency was accompanied by the loss of body weight and BCS. Body condition stagnated longer on the lowest level and was more conform to energy balance than body weight. In conclusion, high efficiency required an increasing partitioning of nutrients to milk yield inclusive mobilisation. Breeding for higher efficiency would exacerbate catabolic state including problems with health and fertility. This highlights the necessity of a broader definition of efficiency in cattle breeding involving parameters like BCS, health and fertility traits.

KEYWORDS: efficiency; energy balance; body condition score; lactation stage; body tissue mobilisation

2.3.2 Introduction

In Austria, average milk yield per lactation steadily increased to 7281 kg in 2015. It has thus more than doubled since 1950 when the lactation yield was 2998 kg (ZAR 2016). The main breed for dairy production is Fleckvieh (FV, dual-purpose Simmental) with 73.3% of performance recorded cows, followed by Brown Swiss (BS) and Holstein Friesian (HF) with 12.0 and 11.7% (ZAR 2016). Over the last few decades, dairy production has become more specialised and intensive along with high genetic gain and higher concentrate proportions in diets (ZuchtData 2016; Knaus 2016). Due to the high economic impact of feed costs (de Haas et al. 2014), efficiency and efficiency related traits (e.g. milk production, feed intake, body condition score, body weight or re-

production traits) have recently gained in importance in the dairy industry (e.g. Veerkamp and Emmans 1995; Pryce et al. 2001). Veerkamp and Emmans (1995) identified feed intake capacity, milk yield, the extent of body tissue mobilisation and energy partitioning between milk and body as main sources of genetic variation in energy efficiency. The increase of milk yield, as it occurred in many countries, would therefore automatically lead to higher efficiency, except cows would become larger and heavier as reported by Hansen (2000). But, breeding for efficiency may also prefer light cows with high mobilisation (e.g. Vallimont et al. 2011). Furthermore, high yielding dairy cows tend to produce milk more efficiently because they partition more energy to milk performance instead to their body reserves (Veerkamp and Emmans 1995; Yan et al. 2006). Energy partitioning via somatotrophic axis for maintaining the homeorhetic state of milk production was reported by Bauman and Currie (1980) and proved by Lucy et al. (2009). The higher the milk production potential, the longer the counter regulation of the catabolic growth hormone was interrupted. Despite increasing energy density in diet, milk performance and catabolic processes were supported during early lactation instead of regaining body tissue. Priority of milk production originally guaranteed the survival of offspring. Extending this priority resulted in an increased energy deficit and therefore tissue mobilisation especially in early lactation (Martens 2013). The extent, to which negative energy balance cannot be reduced by feeding a higher energy diet, is defined as genetically driven (Friggens et al. 2007). Negative energy balance and depletion of body stores had been associated with problems in health and fertility (e.g. Spicer et al. 1990; Lucy 2001; Pryce et al. 2001). Non-esterified fatty acids, pro-inflammatory cytokines and reactive oxygen species additional to the negative energy balance in the peripartal period may lead to stress in the endoplasmic reticulum in the liver (ER stress). This is considered to predispose high yielding dairy cows to develop diseases like ketosis and fatty liver. Furthermore, cows seemed to show differing capabilities to cope with negative energy balance. The activation of hepatic stress response pathways to reduce damages of tissue may be different between dairy cows. Finally, ER stress can promote insulin resistance and lead to hepatic inflammatory processes (Ringseis et al. 2015). A high level of cytokines due to a subclinical inflammation *ante partum* reduces feed intake. This exacerbates the negative energy state in early lactation and ending up in a downward spiral (Menn 2015).

The Federal Association of Austrian Cattle Breeders (ZAR) initiated the project 'Efficient Cow' in 2012 for improving efficiency in Austrian dairy cattle, and for evaluation how this would affect greenhouse gas emissions. The aim of this study was to evaluate the influence of genotype, parity and lactation stage on different efficiency parameters in dairy production, energy balance, and related traits. Within genotype, several groups of FV cows with increasing average Red Holstein (RH) proportion were compared to monitor the impact of RH genetics within the dual-purpose breed FV.

2.3.3 Materials and methods

2.3.3.1 Data recording and calculation

Data was recorded in 2014 from 3634 FV, 1034 HF and 1437 BS cows kept on 161 dairy farms in Austria. Free-stall barns and milking twice a day in a milking parlour system were common. The Austrian milk recording organisations collected additional traits like body weight, body condition score (BCS), heart girth, belly girth and information on diet as well as diet quality at each routine performance recording day. Body weight was recorded as single measurement using mobile

scales of the milk recording organisations. Cows were gathered and entered the scale separately. Data was stored in the Austrian central cattle database. The average herd size of participating farms (32.7 cows) was twice as high as the Austrian average of 16.5 dairy cows (ZAR 2016). It reflected the wide range of herd size in Austria (3.2 to 97.9 cows). Milk recording was done 9 to 11 times a year with on average 9.8 performance recordings per farm. Farms were situated between 300 and 1460 m above sea level in mountainous, flat and hilly areas. Detailed information about herds, farms and performance recording methods is given in Ledinek et al. (2019).

Handling of forage analyses (VDLUFA 1976–2012), nutrient content of concentrate (DLG 1997), and calculation of energy content of forage (GfE 2001) were described in the previous article by Ledinek et al. (2019). Due to the lack of ability to comprehensively measure feed intake on-farm, dry matter intake (DMI) was estimated using the prediction model of Gruber et al. (2004). This given situation was used for developing novel strategies for recording information on diet composition on-farm. Diet composition and feeding systems were additionally considered in the feed intake prediction model. The used prediction model was found to be the most accurate and valid one of five evaluated up-to-date models (Jensen et al. 2015). The validation set included 12 Scandinavian experiments involving 917 dairy cows and 94 treatments. The breeds were Danish/Swedish Red, varying in lactation stages and parity. The use of feed intake prediction showed a possible approach for gaining information under insufficient conditions for measuring. Further details about recording diet composition, feed intake estimation and chemical diet composition can be found in Ledinek et al. (2016), and Ledinek et al. (2019). Energy corrected milk yield (ECM) and energy requirement were calculated using the guidelines of GfE (2001). Daily energy requirements included requirements for maintenance, milk production and pregnancy. Daily energy balance was calculated by subtracting energy requirements from energy intake, expressed in MJ of net energy for lactation (NEL) per day (GfE 2001). Edmonson et al. (1989) defined the applied 5-point system for BCS recording.

The calculation of efficiency parameters was based on the description by Berry and Pryce (2014). As feed intake had to be estimated, residual feed intake could not be considered. In this study efficiency was defined as ratio between output and input and named after the input parameter. Therefore kg ECM per kg metabolic body weight ($BW^{0.75}$) was defined as body weight efficiency, kg ECM per kg DMI as feed efficiency and energy in milk (LE) per energy intake, both expressed in MJ of NEL, as energy efficiency. Energy efficiency additionally considers diet quality and therefore concentrate proportion. A holistic comparison of dual-purpose and specialised dairy types requires additional information about fattening potential etc., but this would extend the scope of the current study.

2.3.3.2 Statistical analysis

The dataset was based on 38,070 performance recordings of 6105 cows on 161 farms. As described in detail in Ledinek et al. (2019), the groups FV, HF and BS included only cows with 100% ancestry of the respective breed. Further, genotypes of FV×RH were defined according to the RH gene proportion. Classes with an average of 6.25% RH genes (FV×RH6.25, 963 cows), 12.5% RH genes (FV×RH12.5, 342 cows), 25% RH genes (FV×RH25, 404 cows), and 68% RH genes (FV×RH5075, 349 cows, combination of the groups FV×RH50 and FV×RH75) were established. This spectrum of FV×RH groups between the two pure genotypes FV (1576 cows) and HF allowed illustrating the influence of the dairy breed RH on the dual-purpose breed FV. It characterises the

specialisation on dairy performance (potential for milk production). Lactation stage included finally twelve 28-day stages (lactation months) and days in milk (DIM) from 1 to 336.

The final model included genotype, parity (1, 2, 3+4, ≥ 5), lactation stage and their interactions as fixed effects. The effect of diet was considered via the fixed effect forage type (1–18) and the management via the fixed effect of farm (1–161). The effect of cow (1–6105) was assumed to be random and nested within genotype and farm. Parameters were analysed using PROC MIXED of SAS 9.4 (SAS 2015), the method REML and the method of Kenward-Roger for the approximation of the denominator degrees of freedom. The chosen default covariance structure VC had the smallest Akaike information criterion. The multiple comparisons were applied using the specification ADJUST = TUKEY with $p < 0.05$ for significant differences. The effect of forage type on efficiency and its related traits was included only as correction factor, but is not topic of this study. Therefore, it is not discussed further.

2.3.4 Results and discussion

2.3.4.1 Effect of genotype and genotype $\times$ lactation stage

Table 1B contains efficiency traits, energy balance and related traits like predicted feed intake, predicted energy intake, milk production, body weight and BCS. Genotype differed in all traits ($p < 0.001$). As feed intake is estimated, energy balance, energy and feed efficiency are partly based on predicted values. Results of predicted and measured traits correspond to each other and are consistent with findings in literature. As in Ledinek et al. (2019) discussed in detail, average body weight and especially BCS declined with specialisation on milk production from FV to HF with increasing RH genes. Production traits like ECM, milk yield, predicted DMI and energy intake increased. The FV groups, especially up to an average of 12.5% RH genes, were biologically similar. BS was located in the range of FV to FV $\times$ RH25 except they were slightly lighter than HF and had a BCS approximately midway between FV and HF. Crude protein, neutral detergent fibre (NDF) and energy density were approximately 155 g, 389 g and 6.53 MJ NEL per kg dry matter (DM) of total diet. Dietary nutrient level and concentrate proportion increased with higher potential for milk production according to the findings of e.g. Dillon et al. (2003). As forage type was kept constantly forage had approximately 132 g crude protein, 446 g NDF and 6.00 MJ NEL per kg DM (Ledinek et al. 2019).

The milk protein content of BS corresponded to the breeding on high protein content in Austrian BS. The decrease of milk protein content from the FV up to an average 25% RH genes to HF was hardly surprising (ZAR 2016). For milk fat, no special trend related to RH gene proportion was found, but the two groups HF and BS had the lowest fat content. In earlier studies, HF cows had lower milk solid contents compared to breeds with lower potential for milk production (Dillon et al. 2003) and lower fat and protein contents than New Zealand HF (Roche et al. 2006; Piccand et al. 2013). The effect occurs within a breed between cows of lower and higher genetic merit for dairy traits, too (Kennedy et al. 2003). It is based on the higher ratio of growth hormone to insulin and the higher level of growth hormone in blood of high yielding cows during lactation (Hart et al. 1978; Hart et al. 1979).

All efficiency parameters (Figure 1B) showed an increasing trend from FV to HF with rising RH genes. Although body weight did not decline until 25% RH genes in Fleckvieh, body weight efficiency increased due to rising ECM. The group BS was located approximately in the midway of FV

and the most efficient groups HF and FV×RH5075. Body weight was lower than of HF, but milk performance was similar to FV. We found that body weight efficiency nearly mirrored BCS. The lower the average BCS, the more efficient the genotypes were. In contrast to this, feed and energy efficiency of BS were similar to FV, because of comparable milk production and feed intake. High yielding cows or breeds do not only have a higher performance and feed intake. They partition more nutrients to milk production than to body reserves (Yan et al. 2006). Feed efficiency ranged between 1.319 kg ECM/kg DMI for BS and 1.381 and 1.383 kg ECM/kg DMI for HF and FV×RH5075, respectively. Thus, HF of the current study was more efficient than HF in commercial Danish dairy herds, but did not reach feed efficiency of the smaller Danish Jerseys (Kristensen et al. 2015). In contrast to this, the Danish HF cows produced more ECM per body weight than all genotypes of the current examination due to their lower body weight (HF: Danish HF 602 vs. Austrian HF 662 kg). In a Swiss breed comparison, New Zealand HF and Swiss HF were most efficient (Piccand et al. 2013). In contrast to the current study, Swiss BS had the same body weight efficiency as Swiss FV. However, Swiss FV is more comparable with FV×RH5075 due to a similar RH proportion. Overall, the cows in the Swiss study produced milk less efficiently than in our and the above mentioned Danish results due to their lower milk production. This shows the difference between high-input and a pasture-based low input system. Pasture-based low input systems aim at high productivity per ha pasture and not per cow (Dillon et al. 1995). Milk performance, the dietary nutrient level as well as the rare use of pure forage diets and pasture confirmed that the project farms belonged to the current upper end of the structural change of Alpine dairy farming (Ledinek et al. 2019). In the last 50 years larger, indoor-feeding, non-seasonal and more specialised dairy production more and more replaced the forage-based and small-scaled one (Knaus 2016). Furthermore, an increasing amount of concentrate reduces the efficiency of converting human-inedible feed stuffs into human-edible products. The area of grassland utilised per ton of milk is positively correlated with efficiency of human-edible feed conversion (Ertl et al. 2015).

Average energy balance ranged between −1.57 (FV×RH12.5) and 3.78 MJ NEL/d (BS). Along with fully recovering from the BCS loss after calving, this result indicates that the Austrian project farms paid attention to feeding diets according to energy requirements. Coffey et al. (2004) and Yan et al. (2006) demonstrated that high yielding cows required energy-dense diets to regain fat stores. The high yielding groups HF and FV×RH5075 seemed to regain their loss of body reserves (BCS; Figure 1B) mainly in late lactation. However, they then had more energy-dense diets due to a higher concentrate proportion but relatively low milk production compared to the other groups. The group HF lost BCS the most. It stagnated longest at its lowest level until DIM 154. The FV groups mobilised less body tissue and regenerated earlier (Ledinek et al. 2019). The group BS, having the lowest feed and energy efficiency, reached positive energy balance on DIM 62. The low feed and energy efficiency of BS was due to a relatively high energy density compared to the milk performance. FV followed on DIM 100. Energy balance of FV×RH25, HF and FV×RH5075 became positive later (between DIM 110 and 120). The strong exploitation of body reserves with increasing milk production or specialisation on dairy traits was confirmed earlier by several other studies (e.g. Coffey et al. 2004; Yan et al. 2006; Friggens et al. 2007).

2.3.4.2 Effect of parity and genotype × parity

Parity affected all traits significantly ($p < 0.001$; Table 1B). Interaction between parity and genotype was significant for most traits (data not shown). However, the order of genotypes within

parity mostly remains the same. In cases when it did not, differences were numerically small and not significant. As described by Ledinek et al. (2019), most traits increased in a degressive way until parity 3+4 determined due to growth and maturing of the cows with progressing age. In parity ≥ 5 traits were slightly lower than in parity 3+4 except increasing body weight.

Due to our findings that higher milk performance and efficiency were based on a higher degree of mobilisation, we assumed to find similar patterns in all parities. In fact BCS and energy balance mirrored performance and efficiency parameters over parities. The decreasing efficiency of the older cows in parity ≥ 5 can be explained by the declining performance. In parity 1 cows partitioned nutrients additionally into growth and maturation as increasing body weight showed. In parity ≥ 5 nutrients were additionally partitioned into body fat tissue, partly visualised by a higher BCS within genotypes. Rising BCS was mainly found in the FV groups. The breeds HF and BS constantly lost BCS from parity 1 to ≥ 5 (data not shown). This observation was confirmed by the conclusions of Coffey et al. (2004): primarily breeding for high milk performance had forced cows to exploit their energy reserves to a higher extent in early lactation than they could regain in their remaining productive life.

In contrast to the other fixed effects parity revealed a difference in development between body weight efficiency vs. feed and energy efficiency. Body weight efficiency followed the degressive development of ECM, body weight and feed intake (Ledinek et al. 2019). Only FV×RH6.25 and HF were most efficient in parity 2. The group FV×RH6.25 failed to exhibit the typical peak of ECM in parity 3+4 and had a constant ECM from parity 2 to ≥ 5 . Daily ECM of HF increased strongly between parity 1 and 2 relatively to body weight. Feed and energy efficiency showed that cows of parity 2 and ≥ 5 were more similar to cows of parity 1. Cows of parity 3+4 had a higher performance than those of parity 2, although predicted DMI per body weight was slightly lower. Their additional energy requirements were only partially met by increasing DMI. In HF cows the strong increase of ECM caused a degressive increase of efficiency up to parity 3+4. Their energy balance developed in the opposite direction and BCS declined even up to parity ≥ 5 . Contrary to this, efficiency as well as BCS of FV×RH6.25 were nearly constant due to the before mentioned low ECM in parity 3+4. Although milk yield is known as important driver of DMI (Kennedy et al. 2003, Gruber et al. 2004) feed intake capacity did not develop sufficiently during production life. Differing heritabilities of DMI (0.16 to 0.49) and of milk performance (0.44 to 0.95) reflect the general relationship (Veerkamp and Koenen 1999).

2.3.4.3 Effect of lactation stage

Table 2B shows the parameters changing over lactation ($p < 0.001$). Highest estimated nutrient and feed intake (21.49 kg DM/d; 161.8 g/kg BW^{0.75}) were observed at DIM 71 together with highest concentrate proportion (33.1%, 6.64 MJ NEL/kg DM) and highest nutrient density of total diet. The NDF content of total diet mirrored the concentrate proportion and ranged between 378 and 406 g/kg DM. Forage intake increased until DIM 321 with 14.99 kg DM/d (Ledinek et al. 2019). Efficiency parameters declined with progressing lactation mainly due to decreasing milk production while body weight increased. Lowest milk protein and fat content were reached on DIM 43 and 71 during the negative energy state. The lactose content developed similar to milk yield. Highest efficiency coincided with highest milk yield and lower feed and energy intake in early lactation. This observed low feed intake during early lactation (Ingvarsen and Andersen 2000) led to a negative energy balance approximately until DIM 110. The cows produced milk

partly independently from nutrient supply by depleting their body reserves. This was described as 'genetically driven body energy change' (Friggens et al. 2007). It ensures the nourishment of calves independent from the situation of the dam (Bauman and Currie 1980; Martens 2013). Bauman and Currie (1980) divided the lactation into thirds: in the first part, energy balance was negative due to priority of milk production. The second part showed a balanced situation. The surplus of energy in the third part was used for regaining body reserves and requirements for pregnancy. Yan et al. (2006) quantified the increasing efficiency of partitioning energy intake to body tissue with progressing lactation. This results in an increase of BCS together with energy retention. Martens (2013) pointed out that extent and duration of negative energy balance in dairy cows became larger in the last decades by breeding for higher (initial) milk yield. In contrast to this, beef cows did not undergo any body weight change (Hart et al. 1975). The long negative state agreed with our findings that cows had an above-average production level compared to the Austrian average (ZAR 2016). The high dietary nutrient level did not prevent loss of body reserves. However, feeding a more energy-dense diet to specialised dairy breeds resulted in a higher proportion of additional energy intake, which was partitioned to milk production instead to body tissue (Yan et al. 2006). Furthermore, high milk performance and negative energy balance or its visible signs like loss of BCS or body weight are connected with decreasing fertility and health (e.g. Lucy 2001; Pryce et al. 2001; Martens et al. 2013). Newer studies discussed the occurrence of an inflammatory state of liver and stress of endoplasmic reticulum during the periparturient period. It is seen as another point within the interrelationships of milk performance, BCS, homeorethnic regulation, lipid metabolism and inflammatory diseases (e.g. Bertoni et al. 2008; Bradford et al. 2015; Gessner et al. 2015). The negative energy balance plays a key role herein (Martens 2013). The high efficiency of the cows in the current study, especially in first third of lactation, was based on depletion of body fat stores.

Beside the effects of energy balance on milk performance, health and fertility, the relationship to body weight and BCS in different stages of lactation was examined (Dillon et al. 2003; Berry et al. 2006). In the current study, BCS reached its nadir on DIM 71 and stagnated until DIM 155. Body weight started to increase earlier at DIM 43 and continuously rose afterwards. This agreed with results of Andrew et al. (1994), who reported lowest body energy content on DIM 77 in HF cows. Similar disagreements between the development of BCS and body weight were observed by e.g. Dillon et al. (2003). The development of both BCS and body weight varied with feeding level (Berry et al. 2006; Yan et al. 2006). In accordance to earlier studies (Andrew et al. 1994; Ledinek and Gruber 2015), body weight may have been influenced by feed intake and water repletion during fat mobilisation.

2.3.5 Conclusion

Among all discussed effects one observation was at common: High efficiency required nutrient partitioning inclusive mobilisation towards milk performance. The higher the potential for milk production, the more efficiently milk was produced, albeit at the expenses of body reserves. High milk performance and therefore high efficiency in the first third of lactation were mainly based on the depletion of body fat stores. It pictured the well-known incidence of a negative energy balance. Therefore breeding for higher efficiency would lead to a longer and more intense negative energy balance including problems with health and fertility. Hence, when design-

ing an efficiency index for cattle breeding, several further traits such as body condition, health, fertility, or fattening potential need to be considered.

The production level of the project farms was notably above the Austrian average, which resulted in energy-dense diets. High milk yield driving efficiency was accompanied by energy-dense diets. Further research is needed to clarify how efficiency on animal level, if it is driven by milk yield and based on energy-dense diets, interacts with a sustainable dairy production and the use of human-edible feed stuffs.

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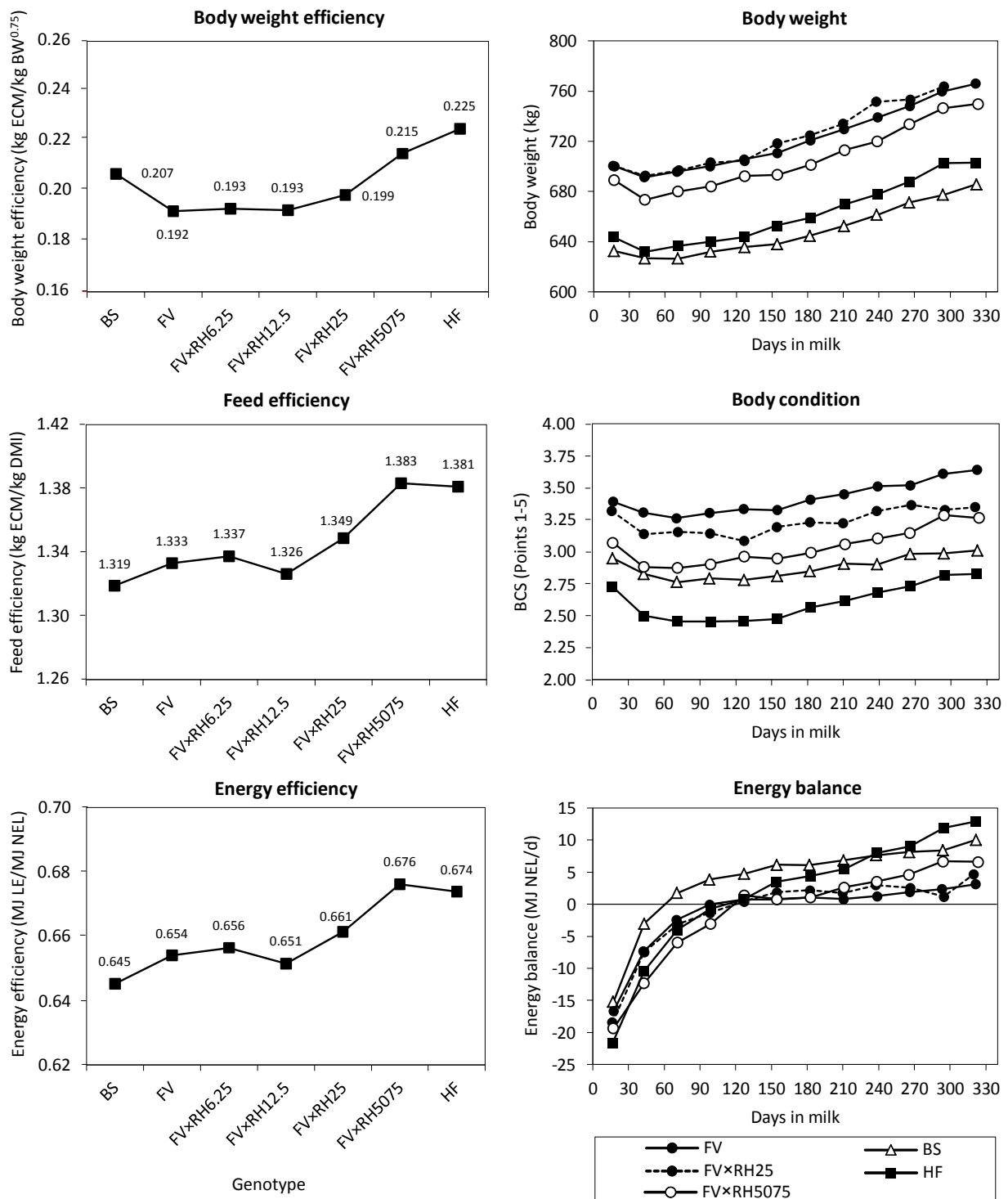


Figure 1B. Effect of genotype on the efficiency parameters of Brown Swiss (BS), Fleckvieh (FV), the FV groups with increasing Red Holstein (RH) genes and Holstein Friesian (HF) as well as the interaction of selected genotypes and lactation stage for body weight, body condition score and energy balance (ECM: energy corrected milk; BW^{0.75}: metabolic body weight; DMI: predicted dry matter intake; LE: energy in milk; NEL: net energy for lactation; BCS: body condition score (Ledinnek et al. 2019)). As DMI was estimated, energy intake, energy balance, feed and energy efficiency are partly based on predicted values.

Table 1B. Effect of genotype and parity on body weight, body condition score, milk production data, predicted dry matter intake, energy balance and efficiency parameters (least squares means).

Trait	Genotype ^a (G)						Parity (P)					RMSE [¶]	p-value	
	FV	FV×RH6.25	FV×RH12.5	FV×RH25	FV×RH5075	HF	BS	1	2	3+4	≥5		G	P
Data set, N = 38,070	9942	5969	2156	2365	2180	6172	9286	10,856	8385	10,865	7964			
Body weight (BW) and body condition (BCS)														
BW, kg	722 ^b	729 ^a	728 ^{a,b}	725 ^{a,b}	706 ^c	662 ^d	649 ^e	644 ^d	698 ^c	727 ^b	744 ^a	57	< 0.001	< 0.001
BCS, Points 1–5	3.42 ^a	3.39 ^a	3.38 ^a	3.24 ^b	3.04 ^c	2.61 ^e	2.88 ^d	3.16 ^a	3.14 ^b	3.13 ^b	3.12 ^b	0.46	< 0.001	< 0.001
Milk traits														
Milk, kg/d	26.3 ^c	26.3 ^c	26.4 ^{b,c}	27.0 ^b	28.9 ^a	29.5 ^a	26.4 ^{b,c}	24.2 ^d	27.5 ^c	29.0 ^a	28.2 ^b	5.4	< 0.001	< 0.001
ECM [†] , kg/d	26.7 ^c	27.0 ^c	26.9 ^c	27.7 ^b	29.3 ^a	29.2 ^a	26.5 ^c	24.5 ^d	28.0 ^c	29.3 ^a	28.6 ^b	5.5	< 0.001	< 0.001
Milk fat, %	4.21 ^b	4.28 ^a	4.22 ^{a,b}	4.28 ^{a,b}	4.22 ^{a,b}	4.09 ^d	4.13 ^{c,d}	4.18 ^b	4.22 ^a	4.20 ^{a,b}	4.22 ^a	0.66	< 0.001	< 0.001
Milk protein, %	3.53 ^b	3.56 ^a	3.55 ^{a,b}	3.55 ^{a,b}	3.47 ^c	3.35 ^d	3.49 ^{b,c}	3.46 ^d	3.55 ^a	3.50 ^b	3.48 ^c	0.28	< 0.001	< 0.001
Milk lactose, %	4.73 ^{b,c}	4.73 ^{b,c}	4.71 ^c	4.74 ^{a,b}	4.73 ^{b,c}	4.73 ^{b,c}	4.75 ^a	4.83 ^a	4.75 ^b	4.70 ^c	4.64 ^d	0.16	< 0.001	< 0.001
Feed intake and energy balance														
DMI [‡] , kg DM/d	19.72 ^c	19.83 ^c	19.87 ^c	20.24 ^b	20.82 ^a	20.86 ^a	19.84 ^c	18.24 ^d	20.48 ^c	21.02 ^a	20.93 ^b	1.58	< 0.001	< 0.001
Energy intake [§] , MJ NEL/d	129.1 ^c	129.7 ^c	130.0 ^c	132.6 ^b	136.7 ^a	137.4 ^a	130.3 ^{b,c}	119.4 ^d	134.2 ^c	138.1 ^a	137.4 ^b	12.7	< 0.001	< 0.001
Energy requirement [#] , MJ NEL/d	130.4 ^b	131.4 ^b	131.2 ^b	133.8 ^a	138.1 ^a	135.5 ^a	126.3 ^c	119.6 ^d	133.4 ^c	139.1 ^a	137.4 ^b	18.20	< 0.001	< 0.001
Energy balance [¶] , MJ NEL/d	−1.22 ^c	−1.57 ^c	−1.39 ^c	−1.07 ^c	−1.12 ^c	1.59 ^b	3.78 ^a	−0.23 ^b	0.76 ^a	−1.06 ^c	−0.04 ^b	13.12	< 0.001	< 0.001
Efficiency parameters														
Body weight eff., kg ECM/kg BW ^{0.75}	0.192 ^d	0.193 ^d	0.193 ^d	0.199 ^c	0.215 ^b	0.225 ^a	0.207 ^{b,c}	0.193 ^d	0.208 ^b	0.211 ^a	0.202 ^c	0.041	< 0.001	< 0.001
Feed efficiency [†] , kg ECM/kg DMI	1.333 ^{b,c}	1.337 ^{b,c}	1.326 ^{b,c}	1.349 ^b	1.383 ^a	1.381 ^a	1.319 ^c	1.333 ^c	1.347 ^b	1.369 ^a	1.338 ^{b,c}	0.205	< 0.001	< 0.001
Energy efficiency [§] , MJ LE/MJ NEL	0.654 ^{b,c}	0.656 ^{b,c}	0.651 ^{b,c}	0.661 ^b	0.676 ^a	0.674 ^a	0.645 ^c	0.654 ^c	0.660 ^b	0.670 ^a	0.655 ^{b,c}	0.102	< 0.001	< 0.001

^{a–e}Least squares means within a row and a fixed effect with different superscripts differ ($p < 0.05$)

FV: Fleckvieh; RH: Red Holstein; 6.25–5075: average proportion of Red Holstein; FV×RH5075: Fleckvieh with an average proportion of 68% Red Holstein; HF: Holstein Friesian; BS: Brown Swiss

[¶]root mean square error

[†]ECM: energy corrected milk (GfE 2001); [‡]DMI: dry matter intake; DM: dry matter; ^{*}feed and energy intake are predicted; [#]NEL: net energy for lactation; [§]LE: energy in milk

BW, BCS, ECM, DMI and energy intake (Ledinek et al. 2019)

Table 2B. Effect of lactation stage on body weight, body condition score, milk production data, predicted dry matter intake, energy balance and efficiency parameters (least squares means).

Trait	Stage of lactation (DIM [†])											p-value		
	1	2	3	3	4	5	6	7	8	9	10	11	DIM	G [‡] × DIM
DIM [†]	17	43	71	99	127	155	183	211	239	266	294	321		
Data set, N = 38,070	2970	3757	3663	3594	3570	3401	3460	3302	3274	3050	2479	1550		
Body weight (BW) and body condition (BCS)														
BW, kg	682	673	677	682	686	692	700	710	721	729	742	742	< 0.001	0.003
BCS, Points 1–5	3.18	3.02	3.00	3.01	3.02	3.05	3.11	3.15	3.21	3.25	3.31	3.33	< 0.001	< 0.001
Milk traits														
Milk, kg/d	32.4	34.8	33.7	31.8	29.9	28.5	26.9	25.2	23.4	21.4	19.8	19.0	< 0.001	< 0.001
ECM [†] , kg/d	33.4	33.5	32.6	31.1	29.8	28.5	27.4	26.0	24.5	22.7	21.2	20.8	< 0.001	< 0.001
Milk fat, %	4.33	3.92	3.90	3.93	4.01	4.06	4.17	4.26	4.33	4.43	4.52	4.60	< 0.001	< 0.001
Milk protein, %	3.34	3.09	3.20	3.32	3.42	3.48	3.53	3.60	3.65	3.72	3.80	3.86	< 0.001	< 0.001
Milk lactose, %	4.77	4.83	4.82	4.79	4.77	4.74	4.71	4.70	4.68	4.67	4.64	4.64	< 0.001	< 0.001
Feed intake and energy balance														
DMI ^{††} , kg DM/d	19.90	21.19	21.49	21.29	20.93	20.59	20.24	19.88	19.56	19.13	18.94	18.86	< 0.001	< 0.001
Energy intake ^{‡‡} , MJ NEL/d	131.4	141.2	143.3	141.5	138.8	136.0	133.1	130.0	127.2	123.2	121.0	120.2	< 0.001	< 0.001
Energy requirement [‡] , MJ NEL/d	149.0	149.4	146.4	141.9	137.6	134.0	130.8	127.0	123.2	119.1	116.0	114.3	< 0.001	< 0.001
Energy balance ^{‡‡} , MJ NEL/d	−17.60	−8.14	−3.08	−0.39	1.18	1.99	2.32	3.02	3.97	4.12	5.01	5.90	< 0.001	< 0.001
Efficiency parameters														
Body weight eff., kg ECM/kg BW ^{0.75}	0.249	0.253	0.245	0.233	0.222	0.211	0.201	0.190	0.177	0.163	0.150	0.147	< 0.001	< 0.001
Feed efficiency [†] , kg ECM/kg DMI	1.659	1.561	1.496	1.445	1.403	1.369	1.336	1.293	1.236	1.172	1.105	1.086	< 0.001	< 0.001
Energy efficiency ^{§†} , MJ LE/MJ NEL	0.808	0.753	0.721	0.699	0.680	0.666	0.653	0.635	0.611	0.585	0.557	0.548	< 0.001	< 0.001

[†]LS-means of day in milk of 28-day classes 1–12

[‡]genotype

[†]ECM: energy corrected milk (GfE 2001); ^{††}DMI: dry matter intake; DM: dry matter; [‡]feed and energy intake are predicted; ^{‡‡}NEL: net energy for lactation; [§]LE: energy in milk

BW, BCS, ECM, DMI and energy intake (Ledinek et al. 2019)

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2.4 Analysis of lactating cows on commercial Austrian dairy farms: Influence of genotype and body weight on efficiency parameters

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Analysis of lactating cows on commercial Austrian dairy farms: Influence of genotype and body weight on efficiency parameters

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2.4.1 Abstract

The aim of this study was twofold: First, to evaluate the influence of body weight on the efficiency of dairy cows, and second, to analyze the current state of dairy cattle populations as part of the Austrian Cattle Breeding Association's Efficient Cow Project. Data of Fleckvieh (FV, dual-purpose Simmental), Fleckvieh × Red Holstein (FV×RH), Holstein (HF) and Brown Swiss (BS) dairy cows (161 farms, 6,098 cows) were collected at each performance recording during the year 2014. In addition to routinely recorded data (e.g. milk yield, fertility, etc.), body weight, body measurements, body condition score (BCS) and individual feed information were also collected. The following efficiency traits were considered: body weight efficiency as the ratio of energy corrected milk (ECM) to metabolic body weight, feed efficiency (kg ECM per kg dry matter intake) and energy efficiency expressed as the ratio of energy in milk to energy intake. The relationship of milk yield to body weight was shown to be non-linear. Milk yield decreased in cows above the 750 kg body weight class for HF, BS and FV×RH with 68% RH genes, but less dramatically and later for FV at 800 kg. This resulted in an optimum body weight for feed and energy efficiency. BS and HF had the highest efficiency in a narrower and lighter body weight range (550–700 kg) due to a stronger curvature of the parabolic curve. Contrary to this, the efficiency of FV did not change as much as it did in the dairy breeds with increasing body weight, meaning that FV had a similar feed and energy efficiency in a range of 500–750 kg. The breed differences disappeared when body weight ranged between 750 and 800 kg. The average body weight of the breeds studied (FV 722 kg, BS 649 and HF 662 kg) was in the optimum range. FV was located at the upper end of the decreasing segment. In conclusion, an optimum body weight range for efficiency does exist, due to the non-linear relationship of milk yield and body weight. Specialized dairy breeds seem to respond more intensively to body weight range than dual-purpose breeds, due to the stronger curvature. Cows with medium weights within a population are the most efficient. Heavy cows (> 750 kg) produce even less milk. A further increase of dairy cows' body weights should therefore be avoided.

2.4.2 Introduction

Over the last decades, milk performance has increased dramatically and resulted in a decline in fertility, vitality and longevity (Knaus 2009). This development has reduced cows' cost effectiveness. In the USA, Bavaria (Germany) and Austria (Knaus 2009), the number of completed lactations has dropped under the calculated critical threshold of four parities (Essl 1982). In Austria, there have been efforts to stop this trend, including introducing a breeding value for longevity in 1995 and a joint genetic evaluation in Austria and Germany in 2002 (Fuerst and Egger-Danner

2002). Cows' body size is also increasing. In the USA, Holstein cows were selected directly for body size to some extent, on the assumption that larger cows are able to produce more milk (Hansen 2000). In Bavaria (Germany), increasing body size in Fleckvieh (dual-purpose Simmental) and Brown Swiss (BS) has been negatively connected to longevity (Krogmeier 2009). In 1966, a long-term experiment with HF cows at the Northwest Experiment Station, University of Minnesota, concerning cow size was initiated and resulted in several studies (e.g. Mahoney et al. 1986; Hansen et al. 1999; Becker et al. 2012). The selected line became larger and heavier, but had higher health costs. Studies, for example Brown et al. (1977), have shown that the highest milk yield was reached in the medium body weight range; large and heavy cows were not found to be advantageous, neither in health and fertility traits, nor in milk production. The relevant genetic relationship between milk yield and body weight is difficult to quantify and varies due to the distorting effects of body tissue mobilization and a lack of sufficient data, but is assumed to be positive (Veerkamp 1998). However heavier cows have to produce more milk to be as efficient as lighter cows to dilute the negative effect of their high body weight and therefore increased maintenance requirements (Hansen et al. 1999; Steinwilder 2009). In countries like Ireland and New Zealand, where dairy cows are bred for the efficient use of pasture, animals are lighter and have a higher body condition, but produce approximately only half of the milk yield (Knaus 2016).

The Federation of Austrian Cattle Breeders (ZAR) initiated the project "Efficient Cow" in 2012 to develop efficiency traits for Austrian cattle breeding. Within this framework, the aims of this study were (1) to examine the influence of body weight and genotype on different efficiency parameters for milk production, (2) to clarify if an optimum body weight for highest efficiency exists and to describe the current state of the examined dairy cattle population and (3) to give recommendations concerning body weight in cattle breeding.

2.4.3 Materials and methods

2.4.3.1 Data recording and calculation

During a one-year recording period in 2014, data from 3,628 Fleckvieh (FV) and FV×RH (Red Holstein), 1,034 HF and 1,436 BS cows kept on 161 dairy farms in Austria were collected. Cows were mostly housed in free-stall barns and milked twice a day in a milking parlor. The Austrian milk recording organizations collected new traits like body weight with a mobile scale, body condition score (BCS), body measurements and information about diet and diet quality for each routine performance recording day. Data was stored in the Austrian central cattle database. Forage was sampled either before feeding or at the start of the project. Samples were taken separately according to conservation method, harvest number (first cutting separately) and botanic origin. On average, the farms had 9.8 milk recordings per year, ranging between 9 and 11 times. The number of reports per cow ranged from 1 to 12 with a mode of 8 and a mean of 6.2 reports. Farms were located between 300 and 1460 m above sea level in flat, hilly and mountainous areas (Ledinek et al. 2019a,b). Herd sizes varied between 3.2 and 97.9 cows, reflecting the wide range of herd size in Austria. The production level and average herd size of the project farms (32.7 cows) were above-average compared to other Austrian farms with 16.5 cows (ZAR 2016).

The handling of forage analyses (VDLUFA 1976), nutrient content of concentrate (DLG 1997) and calculation of energy content of forage (GfE 2001) have been described in detail in a previous

article by Ledinek et al. (2019a). The laboratory for feed analyses of the Chamber of Agriculture in Lower Austria analyzed the forage samples using Weende analysis and the method described by Van Soest et al. (1991). Dry matter intake (DMI) was estimated, because comprehensively measuring feed intake on-farm was not feasible (Gruber et al. 2004; Ledinek et al. 2016). This situation provided the opportunity to develop novel strategies for recording diet composition information on-farm. Feeding system and diet composition were also considered in the feed intake prediction model. The prediction model selected for this study was found to be the most valid and accurate model in a comparison of four up-to-date models (Jensen et al. 2015). A detailed description of recording diet information, feed intake estimation and the results of diet composition can be found in Ledinek et al. (2016), and Ledinek et al. (2019a). Energy corrected milk (ECM) was calculated according to the recommendations of GfE (2001). Body condition was evaluated using the 5-point system by Edmonson et al. (1989).

As recommended by Berry and Pryce (2014), efficiency parameters were calculated as the ratio between output and input and named after the input parameter in the current study. The estimation of feed intake resulted in the exclusion of residual feed intake. Body weight efficiency was calculated as kg ECM per kg metabolic body weight ($BW^{0.75}$), feed efficiency as kg ECM per kg DMI and energy efficiency as energy in milk (LE) per energy intake, both expressed in MJ of NEL. Therefore, energy efficiency takes both diet quality and concentrate proportion into account. This study focused solely on efficiency in dairy production. Considering additional aspects relevant to a holistic (economic) comparison of different genotypes, like fattening potential, health or fertility, would have exceeded the scope of this study.

2.4.3.2 Statistical analysis

The data set during lactation included 37,967 records (milk performance recordings), 161 farms, and 6,098 cows.

Combined genotype-body weight classes were established to cover differing body weight ranges within the genotypes. Body weight classes were set at 50 kg intervals from 450–1000 kg. Cows with a body weight between ≥ 425 and < 475 kg were put in the 450 kg class, cows weighing between ≥ 475 and < 525 kg were in the 500 kg class, etc. The name of each class therefore reflects the average body weight of the animals in that class.

Fleckvieh (FV, 100% FV ancestry, 1,575 cows), Fleckvieh with an average of 25% RH genes (FV×RH25, 404 cows), and Fleckvieh with an average of 68% RH genes (FV×RH5075, 345 cows) were in body weight classes ranging from 500–950 kg. Fleckvieh with an average of 6.25% RH genes (FV×RH6.25, 963 cows) were in body weight classes 500–1,000 kg, and Fleckvieh with an average of 12.5% RH genes (FV×RH12.5, 341 cows) in the body weight classes from 550–950 kg. The body weight classes 450–900 kg were included for the lighter BS and HF cows (both 100% ancestry of the respective breed, 1,436 and 1,034 cows). Lower and higher weight classes were discarded due to insufficient numbers of animals in the respective classes.

Stage of lactation consisted of 12 28-day stages from 1–336 days in milk (DIM).

The following final model for dependent traits (e.g. DMI, BCS, efficiency traits) was used:

$$Y_{ijklm} = \mu + G_{BW_i} + P_j + SL_k + F_l + b_{NELFor} \times NELFor + b_{Conc} \times Conc + Cow_m(F_l) + \varepsilon_{ijklm}$$

where Y_{ijklm} = trait, μ = intercept, G_BW_i = fixed effect of genotype-body weight class (1–70), P_j = fixed effect of parity (1, 2, 3+4, ≥ 5), SL_k = fixed effect of lactation stage (1–12), F_l = fixed effect of farm (1–161), b_{NELFor} = linear regression on energy content of forage ($NELFor$), b_{Conc} = linear regression on concentrate proportion ($Conc$), $Cow_m(F_l)$ = random effect of cow nested within farm and ε_{ijklm} = residual.

Traits were analyzed using PROC MIXED of SAS 9.4 (SAS 2015), the REML method, the Kenward–Roger method and the covariance structure VC causing the smallest Akaike information criterion.

2.4.4 Results

Table 1C contains BCS, milk production, estimated DMI and energy intake, while DMI per kg body weight and efficiency parameters can be found in Table 2C. The root mean square errors are shown separately (Table 3C). Apart from energy content of forage on BCS ($P = 0.145$), all effects included in the statistical model influenced all dependent traits significantly ($P < 0.001$). The efficiency parameters, DMI, ECM and BCS of selected genotypes are shown in Figure 1C.

Average milk production, DMI and efficiency parameters increased for the most part continuously together with rising RH genes from FV to HF as previously described in detail (Ledinek et al. 2019a,b). BS had a lower feed and energy efficiency than FV. For most traits, BS came in between the two genotypes FV and HF.

Feed and energy intake increased up to 750 kg body weight and then tended to stagnate or even to decline, especially in the genotypes with a high proportion of specialized dairy breeds (FV×RH5075, HF and BS). Furthermore, genotypes were similar in the very light and the very heavy body weight classes. This development was found to be even stronger when DMI was calculated relative to body weight. The most significant change and therefore strongest curvature again occurred in the specialized dairy genotypes. A look at milk production (Figure 1C) could explain this pattern: The highest production was reached not in the heaviest body weight classes, but in the medium ones. The FV groups with up to an average of 25% RH genes reached ECM peak at 800 kg, except for FV×RH6.25, the lighter FV×RH5075, HF and BS, which peaked earlier at 750 kg. After the peak, the decline of milk yield together with rising body weight continued and differences between dual-purpose types and dairy types vanished.

This pattern was also observed for efficiency parameters, although body weight efficiency differed from feed and energy efficiency. HF produced the most ECM per kg body weight in the 500–650 kg range, BS in the lightest classes at 450–650 kg. In contrast, the efficiency of FV and FV×RH6.25 declined slightly from the start, but remained on a similar level until reaching the 650 kg body weight class. The FV groups with up to an average of 12.5% RH genes showed the lowest loss of body weight efficiency with increasing weight.

Although breed differences in feed and energy efficiency vanished again at a weight of 800 kg, peak efficiency shifted to cows with medium weight. Optimum range of BS and HF was 550–700 kg, peaking between 550 and 650 kg. Contrary to this, efficiency of FV remained steady from 500–750 kg, with the highest efficiency at 600 kg. Efficiency declined increasingly, and was observable starting from the body weight classes 750–800 kg.

Body condition (Figure 1C) rose in a nearly linear fashion with increasing body weight. In the optimum range, FV had a BCS of 2.63–3.49 points, HF of 2.28–2.76 points and BS of 2.64–3.05 points.

2.4.5 Discussion

The non-linear relationship between milk yield and body weight and the stronger curvature of the specialized dairy groups (FV×RH5075, BS and HF) give rise to the question of how these traits are connected to each other.

In the current study, body weight and milk yield were phenotypically correlated to a low degree of 0.12. Due to the non-linear relationship, it would be a mistake to assume a failing connection between the two traits. Enevoldsen and Kristensen (1997) found nearly nonexistent negative and positive correlations within Red Danish × Jerseys, Jerseys and Danish Friesians. Veerkamp et al. (2000) found slightly higher positive phenotypic relationships in the first fifteen weeks of lactation.

Published results on genetic relationships vary as well. In earlier studies (Mason et al. 1957; Hooven et al. 1968), positive relationships were reported, while Veerkamp (1998) revealed a range between -0.41 and 0.45 in his review. Veerkamp (1998) attributed this large variation to differences in data recording times and insufficient measurements in the included studies. Furthermore, the strong connection of body weight to BCS and therefore to mobilization dilutes the actual effect. After the genetic adjustment for BCS, the correlation between body weight and milk yield was reported to be medium positive (Veerkamp 1998). This would confirm the findings of another review (Hansen 2000) that not only milk production but also sharpness and body size of US Holstein cows has increased over recent decades. In a long-term experiment concerning body size, large cows suffered more from claw and leg diseases due to their higher body weight (Hansen et al. 1999). Furthermore, a previous study within this project showed that larger cows required more health care (Mahoney et al. 1986). In Bavaria (Germany), BS and FV cows have increased in body size over the last decades (Krogmeier 2009). Krogmeier (2009) also found a negative relationship between body size and longevity. Comparisons of body weight data in more recent Austrian studies (Gruber and Stegellner 2015; Ledinek et al. 2019a,b) with an older study (Haiger et al. 1983) seem to confirm an increasing trend in body weight in BS and HF. However, the body weight trend could also be affected by overlaying effects. For FV, the increasing selection for dairy traits may have resulted in cows with less muscle mass and BCS but perhaps with larger frames; on the other hand, crossbreeding with lighter Red Holstein was common.

In the current study, the phenotypic correlations between body weight and efficiency were -0.18 for body weight efficiency, -0.11 for feed efficiency and -0.13 for energy efficiency. Prendiville et al. (2009) reported a significantly stronger relationship with -0.46 to -0.50 for their efficiency parameters, which went along with a stronger correlation between body weight and milk yield in a similar range. Dickinson et al. (1969) found a relationship between body weight and energy efficiency of -0.27, and for chest depth, heart girth and body length between -0.21 and -0.38. Their observation that energy efficiency decreases linearly with body weight, while changes in heart girth and body weight cause a quadratic effect, was particularly interesting. Vallimont et al. (2011) confirmed these phenotypic findings with even stronger negative genetic correlations of various efficiency parameters from -0.64 to -0.66 and concluded that larger and fatter cows were

less efficient. Furthermore, heavier cows have to produce more milk to be as efficient as lighter cows to dilute the effect of their increasing maintenance requirements (Steinwilder 2009). As feed intake increases at a rate of 0.22 kg per additional kg milk (Gruber et al. 2004), heavier cows need a higher quality diet or they have to mobilize body tissue to reach an “efficient” milk yield (Steinwilder 2009). Figure 1C shows that heavier cows have a lower feed intake per kg BW^{0.75} than lighter and medium-weight animals.

The finding that having medium-weight cows in a population is optimal has also been confirmed by much older studies (Hooven et al. 1968; Miller and Hooven 1969; Brown et al. 1977). Hansen et al. (1999) compared lighter and heavier HF lines and concluded that due to frequent problems in health and fertility of heavy cows, an optimum body weight range may exist. As Figure 1C shows, dry matter intake and milk yield behave differently with regard to their correlation with body weight. Dry matter intake does increase with increasing body weight over its total range, but to a decreasing extent. Contrary to this, milk yield declines in high body weight classes. As a consequence, efficiency parameters reach their maximum not at the lowest or highest body weights, but somewhere in between, more towards the lower end of the weight range. The somatotrophic axis controls nutrient partitioning between milk production and body tissue, mainly through the hormones somatotropin and the insulin-like growth factor (Lucy et al. 2000, 2009). A high potential for milk production reduces body condition within and among breeds (e.g. Buckley et al. 2000; Dillon et al. 2003; Ledinek et al. 2019b). Consequently, the precondition for a large and heavy body (high body weight and BCS) is the genetic potential for partitioning nutrients into growth and body tissue to a higher extent. This explains why cows in the heavier body weight classes with concurrent higher BCS (Figure 1C) produced less milk relative to their weight. If they produced relatively more ECM, they would be large-framed dairy types with low BCS. Veerkamp (1998) described a negative genetic association between milk yield and BCS. After the genetic adjustment for BCS, the moderately positive genetic association between milk yield and body weight was in line with the positive relationships between milk yield and body size measurements.

In the current study, the higher the gene proportion of specialized dairy breeds, the more the genotypes responded to the range of body weight. Corresponding results were found in a study by Gruber et al. (2017) based on data from German and Austrian research institutes. Somatotropin and the insulin-like growth factor control many aspects of lactation, growth and fertility in cattle (Lucy et al. 2000). The selection for milk production changed the nutrient partitioning mechanisms (Lucy et al. 2009) due to the high metabolic priority given to milk production (Bauman and Currie 1980). This suggests that the relationship between feed intake, ECM and body weight is not the same in dual-purpose and dairy breeds due to differing nutrient partitioning as shown in the current study. Resources like nutrients and energy are primarily put into performance in high-yielding dairy cows (Huber 2018). Not only inadequate management (Huber 2018) but also an inadequate nutrient intake in the first third of lactation (Bauman and Currie 1980) limit available resources and make nutrients scarce, especially for maintenance (body, BCS), fertility and health (Huber 2018). In specialized dairy cows, a small shift in priority towards body weight and BCS along the body weight range probably has a stronger effect on nutrient partitioning towards milk yield. This explains the increasing dependency of efficiency on body weight with increasing specialization for milk production in the current study. During lactation, high-yielding cows have higher levels of growth hormones, non-esterified fatty acids (NEFA) and β -

hydroxybutyric acid and lower levels of insulin in the blood (Hart et al. 1978). This is accompanied by increased body tissue mobilization. Unlike in low-yielding cows, levels of growth hormones and NEFA are significantly reduced in the dry period, while glucose levels rise. As a result, changes in e.g. milk yield, body weight, endocrine and energy state are more pronounced in high-yielding than in lower-yielding cows.

These indications led to the assumption that the increasing body weight classes within a breed may reflect the spectrum of potential in dairy traits, with a higher sensitivity of dairy types to body weight range. However, it must be emphasized that for animals with a low BCS, it was not possible to differentiate between light dairy types and cows that had previously mobilized large amounts of body tissue.

Nevertheless, the groups with a higher proportion of specialized dairy breeds only benefited from their superiority in milk production in the medium body weight range as compared to the dual-purpose types. The average body weight of the FV groups with an average of up to 25% RH genes was between 722 and 729 kg, and 662 and 649 kg of HF and BS respectively in the overall analysis (Ledinek et al. 2019a,b). Therefore, the lighter specialized dairy breed groups were actually at the peak of their optimum nutrient efficiency, while the FV groups with an average of up to 12.5% RH genes as dual-purpose types were located on the upper end of the decreasing segment. FV×RH25 was found to exceed its optimum range between 500 and 700 kg due to the stronger curvature. The lighter groups HF, BS and FV×RH5075 were near the upper end of their optimum range of body weight efficiency. The groups FV, FV×RH6.25 and FV×RH25 exceeded their optimum range. Furthermore, another study conducted as part of the current project (Köck et al. 2018) revealed a medium positive genetic correlation between lameness and body weight. Heavier cows may have more problems with lameness than lighter ones.

2.4.6 Conclusions

The relationship between milk yield and body weight was found to be non-linear. Heavy and very light cows produced less milk than cows of medium body weight. The non-linear relationship between milk production and body weight resulted in an optimal body weight for highest feed and energy efficiency in the medium body weight range of the population. The specialized dairy breeds seemed to respond more intensively to body weight range than dual-purpose breeds. Their superiority in feed and energy efficiency was only observable in the medium body weight range within populations. In Austria, HF and BS have currently reached their optimum of nutrient efficiency. FV is still within the optimum range of body weight, but is reaching the top end. As optimum body weight efficiency is located towards the lighter body weight range, all genotypes are too heavy as to be at the peak of optimum.

Therefore, further increases in body weight of all breeds with regard to nutrient and body weight efficiency cannot be recommended. A broader definition of efficiency including additional aspects like health, fertility or fattening potential should be investigated in the future.

Author contributions. All authors made substantial contributions to the project "Efficient Cow" and manuscript preparation. FS and MM programmed the database for on-farm data collection. KZ and FS coordinated the data collection. MR, KK and LG supported ML during data processing. ML analyzed the data in close collaboration with LG. ML prepared the manuscript with support from LG and BFW. CED was project manager. BFW, CED and LG advised ML during the project.

Data availability. The data sets analyzed during the current study are not publicly available as information contained therein could compromise the privacy of third parties.

Competing interests. The authors declare that they have no conflicts of interest.

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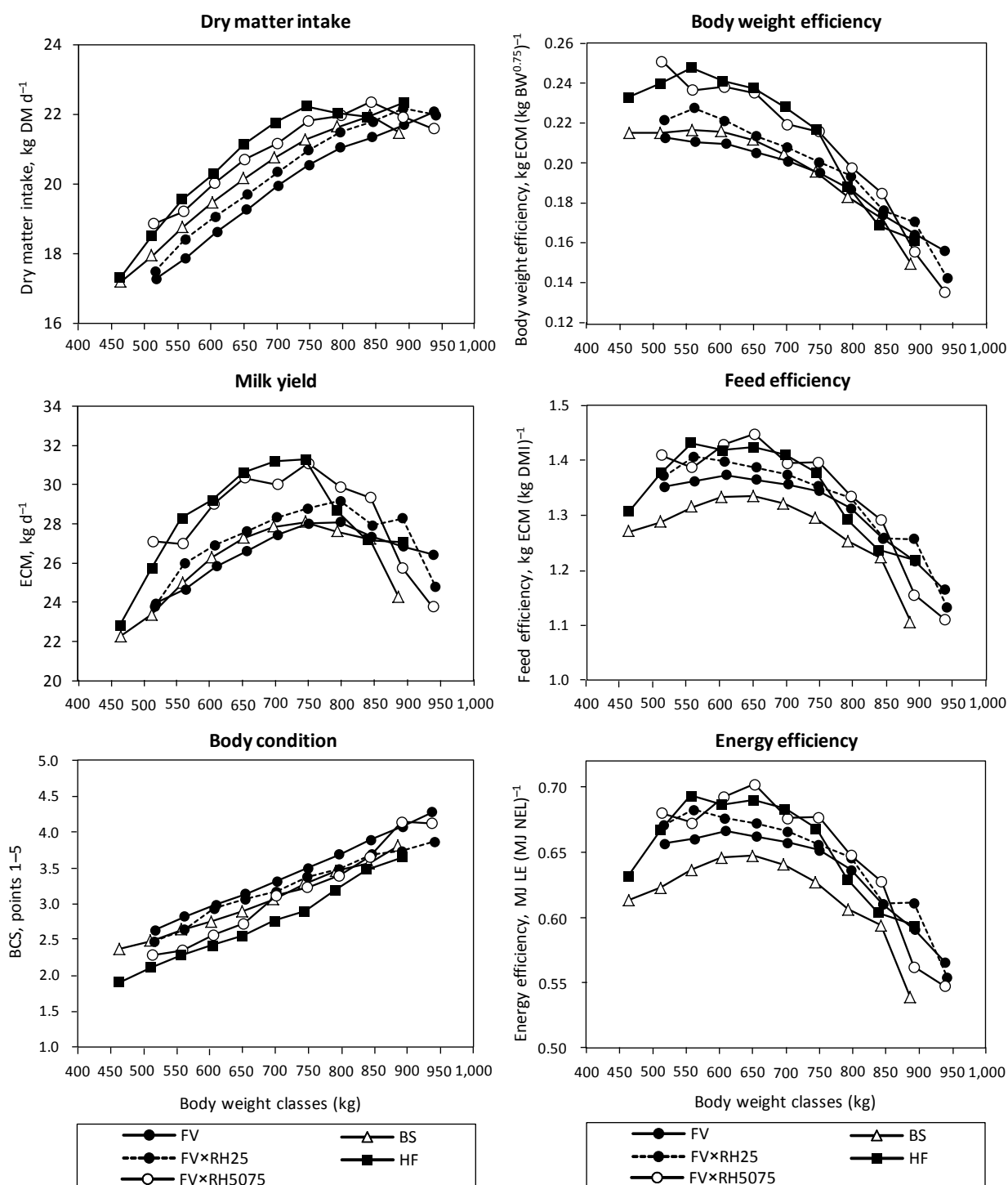


Figure 1C. Effect of body weight on feed intake, milk production, BCS, body weight efficiency, feed efficiency and energy efficiency (LE: Energy in milk) of Brown Swiss (BS), Fleckvieh (FV), the selected FV groups with increasing Red Holstein (RH) genes FV×RH25 and FV×RH5075 as well as Holstein Friesian (HF).

Table 1C. Effect of genotype × body weight on BCS, energy corrected milk, feed and energy intake (least squares means).

Trait†	Genotype‡	Body weight classes (450–1,000 kg)											
		450	500	550	600	650	700	750	800	850	900	950	1,000
Data set (N = 37,967)		81	680	2,151	5,039	7,731	8,170	6,668	4,301	2,061	832	232	21
Body condition, points 1–5													
	FV		2.63	2.82	2.99	3.13	3.31	3.49	3.68	3.89	4.07	4.28	
	FV×RH6.25		2.54	2.65	2.91	3.08	3.28	3.46	3.63	3.81	4.07	4.24	4.49
	FV×RH12.5			2.89	2.98	3.11	3.22	3.39	3.59	3.77	3.92	4.39	
	FV×RH25		2.47	2.64	2.93	3.06	3.16	3.37	3.48	3.69	3.73	3.86	
	FV×RH5075		2.28	2.35	2.56	2.72	3.12	3.23	3.39	3.65	4.14	4.12	
	HF	1.90	2.11	2.28	2.42	2.55	2.76	2.89	3.19	3.47	3.64		
	BS	2.37	2.48	2.64	2.75	2.89	3.05	3.28	3.46	3.56	3.80		
ECM, kg d ^{−1}													
	FV		23.9	24.6	25.8	26.6	27.4	28.0	28.1	27.4	26.8	26.4	
	FV×RH6.25		23.7	24.9	25.8	26.8	27.4	28.4	28.2	27.4	26.1	24.2	24.0
	FV×RH12.5			25.7	25.1	26.8	28.5	28.5	28.8	27.8	25.6	24.8	
	FV×RH25		23.8	26.0	26.9	27.6	28.3	28.8	29.2	27.9	28.3	24.8	
	FV×RH5075		27.1	27.0	29.0	30.4	30.0	31.1	29.9	29.3	25.7	23.8	
	HF	22.8	25.7	28.3	29.2	30.6	31.2	31.3	28.7	27.2	27.1		
	BS	22.2	23.4	25.0	26.3	27.3	27.9	28.1	27.6	27.2	24.2		
Dry matter intake, kg DM d ^{−1}													
	FV		17.28	17.87	18.62	19.27	19.96	20.55	21.05	21.35	21.70	22.07	
	FV×RH6.25		17.47	17.99	18.68	19.36	19.93	20.64	21.09	21.39	21.75	21.50	22.09
	FV×RH12.5			18.29	18.59	19.45	20.30	20.76	21.28	21.46	21.70	21.78	
	FV×RH25		17.48	18.41	19.07	19.69	20.35	20.97	21.50	21.79	22.17	21.98	
	FV×RH5075		18.86	19.21	20.04	20.71	21.17	21.82	21.97	22.36	21.93	21.59	
	HF	17.31	18.52	19.57	20.29	21.14	21.76	22.24	22.04	21.93	22.35		
	BS	17.20	17.93	18.76	19.47	20.16	20.75	21.28	21.65	21.97	21.47		
Energy intake, MJ NEL d ^{−1}													
	FV		114.7	118.7	123.5	127.5	132.1	136.0	139.3	141.1	143.3	145.6	
	FV×RH6.25		116.3	119.7	123.8	128.2	132.0	136.5	139.6	141.5	143.5	142.0	145.6
	FV×RH12.5			121.7	123.0	128.8	134.4	137.4	140.8	141.8	144.0	143.3	
	FV×RH25		115.8	121.8	126.3	130.4	134.7	138.8	142.3	144.3	146.7	145.2	
	FV×RH5075		125.1	127.0	132.7	137.1	140.2	144.5	145.3	147.8	145.0	142.6	
	HF	114.5	122.6	129.4	134.3	140.1	144.2	147.4	145.9	145.1	148.1		
	BS	115.1	119.2	124.5	129.0	133.5	137.3	140.9	143.4	145.4	141.7		

† ECM: energy corrected milk (GfE, 2001); DM: dry matter; NEL: net energy for lactation

‡ FV: Fleckvieh; RH: Red Holstein; 6.25–25: average proportion of Red Holstein; FV×RH5075: Fleckvieh with an average proportion of 68% Red Holstein; HF: Holstein Friesian; BS: Brown Swiss

Table 2C. Effect of genotype × body weight on dry matter intake per kg body weight and efficiency parameters (least squares means).

Trait†	Genotype‡	Body weight classes (450–1,000 kg)											
		450	500	550	600	650	700	750	800	850	900	950	1,000
Data set (N = 37,967)		81	680	2,151	5,039	7,731	8,170	6,668	4,301	2,061	832	232	21
Dry matter intake, g (kg BW ^{0.75}) ^{−1}													
	FV		156.0	153.3	151.3	148.7	146.2	143.3	140.1	136.0	132.9	130.4	
	FV×RH6.25		157.1	154.5	152.4	149.6	146.2	144.0	140.5	136.7	132.8	127.0	126.2
	FV×RH12.5			158.2	151.8	150.3	148.7	144.6	141.6	136.6	132.1	128.0	
	FV×RH25		159.9	160.2	156.3	152.2	149.3	146.3	142.9	138.1	134.5	127.4	
	FV×RH5075		174.2	167.4	164.1	160.4	155.2	152.1	145.9	141.9	133.6	124.9	
	HF	173.6	171.6	170.7	166.9	164.2	159.9	155.2	146.1	137.9	134.2		
	BS	167.0	164.3	162.3	159.5	156.4	152.8	149.0	144.2	139.7	131.9		
Body weight eff., kg ECM (kg BW ^{0.75}) ^{−1}													
	FV		0.213	0.211	0.210	0.205	0.201	0.195	0.187	0.174	0.165	0.156	
	FV×RH6.25		0.210	0.213	0.211	0.208	0.201	0.198	0.188	0.175	0.159	0.145	0.139
	FV×RH12.5			0.222	0.206	0.208	0.208	0.199	0.192	0.177	0.155	0.146	
	FV×RH25		0.222	0.228	0.221	0.214	0.208	0.201	0.194	0.176	0.171	0.143	
	FV×RH5075		0.251	0.237	0.238	0.235	0.220	0.216	0.198	0.185	0.156	0.136	
	HF	0.233	0.240	0.248	0.241	0.238	0.228	0.217	0.188	0.169	0.162		
	BS	0.215	0.215	0.217	0.216	0.212	0.205	0.196	0.183	0.172	0.150		
Feed efficiency, kg ECM (kg DMI) ^{−1}													
	FV		1.351	1.361	1.373	1.365	1.356	1.344	1.312	1.257	1.216	1.163	
	FV×RH6.25		1.321	1.360	1.366	1.368	1.355	1.359	1.316	1.257	1.179	1.102	1.064
	FV×RH12.5			1.389	1.337	1.364	1.381	1.352	1.330	1.272	1.135	1.109	
	FV×RH25		1.371	1.406	1.398	1.387	1.374	1.352	1.332	1.258	1.257	1.131	
	FV×RH5075		1.409	1.387	1.429	1.448	1.395	1.396	1.334	1.291	1.154	1.109	
	HF	1.306	1.377	1.431	1.418	1.424	1.410	1.377	1.292	1.237	1.218		
	BS	1.270	1.287	1.315	1.333	1.334	1.321	1.294	1.252	1.222	1.104		
Energy efficiency, MJ LE (MJ NEL) ^{−1}													
	FV		0.657	0.660	0.666	0.662	0.658	0.652	0.637	0.610	0.591	0.566	
	FV×RH6.25		0.639	0.658	0.662	0.663	0.657	0.660	0.639	0.610	0.573	0.533	0.514
	FV×RH12.5			0.669	0.648	0.662	0.669	0.656	0.645	0.617	0.549	0.537	
	FV×RH25		0.671	0.683	0.676	0.672	0.666	0.656	0.646	0.610	0.611	0.554	
	FV×RH5075		0.680	0.673	0.692	0.702	0.676	0.677	0.648	0.628	0.562	0.547	
	HF	0.632	0.667	0.694	0.687	0.690	0.684	0.668	0.629	0.604	0.594		
	BS	0.614	0.623	0.637	0.646	0.647	0.641	0.627	0.606	0.594	0.539		

† BW^{0.75}: metabolic body weight; ECM: energy corrected milk (GfE, 2001); DMI: dry matter intake; LE: energy in milk, NEL: net energy for lactation

‡ FV: Fleckvieh; RH: Red Holstein; 6.25–25: average proportion of Red Holstein; FV×RH5075: Fleckvieh with an average proportion of 68% Red Holstein; HF: Holstein Friesian; BS: Brown Swiss

Table 3C. Root mean square error of efficiency and production traits.

Trait†	RMSE‡
Body condition, points 1–5	0.4
ECM, kg d ⁻¹	5.5
Dry matter intake, kg DM d ⁻¹	1.16
Energy intake, MJ NEL d ⁻¹	7.9
Dry matter intake, g (kg BW ^{0.75}) ⁻¹	8.3
Body weight eff., kg ECM (kg BW ^{0.75}) ⁻¹	0.040
Feed efficiency, kg ECM (kg DMI) ⁻¹	0.208
Energy efficiency‡, MJ LE (MJ NEL) ⁻¹	0.102

† ECM: energy corrected milk (GfE, 2001); DM: dry matter; NEL: net energy for lactation; BW^{0.75}: metabolic body weight; DMI: dry matter intake; LE: energy in milk

‡ root mean square error

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2.5 Genetic analysis of efficiency traits in Austrian dairy cattle and their relationships with body condition score and lameness

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Genetic analysis of efficiency traits in Austrian dairy cattle and their relationships with body condition score and lameness

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2.5.1 Abstract

This study is part of a larger project whose overall objective is to evaluate the possibilities for genetic improvement of efficiency in Austrian dairy cattle. In 2014 a one-year data collection was carried out. Data of 6,519 cows kept on 161 farms were recorded. Besides routinely recorded data (e.g. milk yield, fertility, disease data, etc.), data of novel traits [e.g. body weight (BW), body condition score (BCS), lameness score, body measurements, etc.] and individual feeding information and feed quality were recorded at each test-day. The specific objective of this study was to estimate genetic parameters for efficiency (related) traits and to investigate their relationships with BCS and lameness in Austrian Fleckvieh, Brown Swiss and Holstein cows. The following efficiency (related) traits were considered: energy-corrected milk (ECM), BW, dry matter intake (DMI), energy intake (INEL), ratio of milk output to metabolic body weight ($ECM/BW^{0.75}$), ratio of milk output to dry matter intake (ECM/DMI) and ratio of milk energy output to total energy intake (LE/INEL, LE = energy in milk). For Fleckvieh, the heritability estimates of the efficiency (related) traits ranged from 0.11 for LE/INEL to 0.44 for BW. Heritabilities for BCS and LAME were 0.19 and 0.07, respectively. Repeatabilities were high and ranged from 0.30 for LE/INEL to 0.83 for BW. Heritability estimates were generally lower for Brown Swiss and Holstein. Repeatabilities were in the same range as for Fleckvieh. In all three breeds, more efficient cows were found to have a higher milk yield, lower BW, slightly higher DMI and lower BCS. Higher efficiency was associated with slightly less lameness problems, most likely due to the lower BW (especially in Fleckvieh) and higher DMI of the more efficient cows. Body weight and BCS were positively correlated with each other. Therefore, when selecting for a lower BW, BCS is required as additional information since otherwise no distinction between large animals with low BCS and smaller animals with normal BCS is possible.

Keywords: efficiency, body condition score, lameness, genetic parameter

2.5.2 Introduction

The dairy industry is under constant pressure to further improve production efficiency. There is also a greater emphasis being placed on reducing the negative impacts of dairy production on the environment. Emissions of greenhouse gas and nutrient losses to the environment should be reduced (Connor 2015). Improving feed efficiency provides a way to tackle these two challenges. The focus is on how much milk is produced from a feed unit and not the performance per animal (VandeHaar 2014).

Feed efficiency is a complex trait, with many definitions in lactating dairy cows. Efficiency can be expressed as ratio-based traits (e.g. ratio of milk output to feed input) and residual-based traits (e.g. residual feed intake) (Berry and Crowley 2013). However, the difficulty of recording feed

intake hinders direct selection for feed efficiency. As an alternative, the use of moderately to highly correlated indicator traits (e.g. milk yield, BW) has been suggested (Berry and Crowley 2013).

The Federation of Austrian Cattle Breeders initiated the project 'Efficient Cow' at the end of the year 2012 with a one-year data collection in 2014. Besides routinely recorded data (e.g. milk yield, fertility, disease data, etc.), data of novel traits (e.g. BW, BCS, lameness score, body measurements, etc.) and individual feeding information and feed quality were recorded at each test-day. Data were recorded into the Austrian central cattle database following extensive plausibility checks. The overall goal of this project was to develop and evaluate efficiency traits in dairy cattle breeding considering Austrian circumstances. Farms were selected to cover the diverse production environments in Austria ranging from mountainous regions to intensive farms in climatically favourable regions. Despite this, the average herd size with 32.6 cows was approximately twice as high as the Austrian average (Steininger et al. 2015).

Detailed phenotypic analysis results of the 'Efficient Cow' data are given by Ledinek et al. (2019a,b,c). The objectives of this study were to estimate genetic parameters for ECM, BW, DMI, energy intake (INEL) and efficiency traits, and to investigate their relationships with BCS and lameness (LAME) based on data from the 'Efficient Cow' project.

2.5.3 Materials and methods

2.5.3.1 Data

Data of routinely recorded milk yield, as well as data of novel traits (BW, BCS and LAME) and individual feeding information and feed quality, recorded by trained staff from the milk recording organisations at each test-day (approximately every 5 weeks), was available from the 'Efficient Cow' project from January 2014 to December 2014. Further information about recording diet information, handling of forage analyses, nutrient content of concentrate, and calculation of energy content of forage is given by Ledinek et al. (2016, 2019a). In total 45,944 records from 6,519 cows from 161 herds were available.

2.5.3.2 Traits

Energy-Corrected Milk. Milk yield was standardized to ECM at each test-day according to the recommendations of GfE (2001) as follows:

$$ECM = (0.38 \times \text{fat percentage} + 0.21 \times \text{protein percentage} + 0.95) / 3.2 \times \text{Milk yield}$$

Body Weight. In Austria standard housing systems for dairy cows are without equipment for weighing routinely. During the observation period of the project all cows were weighed at each test-day. If no scale was available on-farm, a mobile device was used.

Dry Matter Intake. As individual feed intake was impossible to measure on-farm, DMI at each test-day had to be estimated. For this purpose the prediction model no. 1 of Gruber et al. (2004) was used:

$$DMI = 3.878 + \text{Country} \times \text{Breed} + \text{Parity} + DIM + bBW \times BW + bMilk\ yield \times \text{Milk yield} + bConcentrate\ amount \times \text{Concentrate amount} + 0.858 \times NEL\ Forage$$

The model considers the fixed effects of country and breed, parity, DIM and the regression coefficient for the energy content of forage (*NEL Forage*). Depending on the day in milk, the regres-

sion coefficients (b) for BW, milk yield and amount of concentrate have to be calculated. Feeding information was recorded for each cow at each test-day. Dairy cow rations and forage analyses were recorded and included in the prediction as well. A more detailed description of the model and calculation is given by Ledinek et al. (2016). Jensen et al. (2015) evaluated the up-to-date feed intake models of NRC (2001), Volden et al. (2011), TDMI-Index (Huhtanen et al. 2011), Wageningen-DCM (Zom et al. 2012a,b) and Gruber model no. 5 (Gruber et al. 2004) and found the Gruber model to be the most accurate one. In this study model no. 1 was chosen to take advantage of the high coefficient of determination ($R^2 = 86.7\%$) and the low residual standard deviation (RSD = 1.32 kg dry matter) compared to prediction model no. 5 ($R^2 = 83.5\%$, RSD = 1.46 kg dry matter) (Gruber et al. 2004).

Energy Intake. For each cow and test-day energy intake was calculated as follows, whereas DMI was estimated according to the model of Gruber et al. (2004):

$$INEL = DMI \times \text{energy concentration MJ NEL/kg DM}$$

Efficiency Traits. Calculation of efficiency parameters was based on the description of Berry and Pryce (2014). As feed intake had to be estimated, residual feed intake could not be considered, therefore only ratio-based efficiency traits were investigated. Efficiency at each test-day was defined as ratio of milk output to metabolic body weight ($ECM/BW^{0.75}$, body weight efficiency), ratio of milk output to dry matter intake (ECM/DMI , feed efficiency) and ratio of milk energy output to total energy intake ($LE/INEL$, LE = energy in milk, energy efficiency).

Body Condition Score. Body condition score was recorded at each test-day on a scale from 1 (severe underconditioning) to 5 (severe overconditioning) in increments of 0.25 (Edmonson et al. 1989).

Lameness. Lameness was recorded at each test-day using the scoring system by Sprecher et al. (1997) with 1 = normal, 2 = mildly lame, 3 = moderately lame, 4 = lame and 5 = severely lame.

2.5.3.3 Data Edits

Analyses were carried out for Fleckvieh, Brown Swiss and Holstein cows with a maximum foreign gene proportion of 25% from all parities and only data from 5-365 DIM were considered. Dry cows were excluded from the analyses. After edits, in total 37,525 records from 5,942 cows (3,312 Fleckvieh, 1,478 Brown Swiss and 1,152 Holstein) were used for analyses. A summary of statistics of the analyzed data sets is given in Table 1D. Animal pedigree files were generated for each breed by tracing back as many generations as possible for cows with records. The number of animals within each pedigree was 34,842, 15,598 and 15,525 for Fleckvieh, Brown Swiss and Holstein, respectively.

2.5.3.4 Models

Data were analyzed with univariate and bivariate linear animal models using the average information-restricted maximum likelihood (AI-REML) procedure in the DMU package (Madsen and Jensen 2008). Breeding values were obtained from univariate analyses. The following model was applied to all traits:

$$\mathbf{y} = \mathbf{X}\boldsymbol{\beta} + \mathbf{Z}_h\mathbf{h} + \mathbf{Z}_{pe}\mathbf{pe} + \mathbf{Z}_a\mathbf{a} + \mathbf{e},$$

where $\mathbf{y}$ is a vector of observations; $\boldsymbol{\beta}$ is a vector of systematic effects, including fixed effects of herd, year-season of calving, parity-age at calving, parity-lactation stage, parity-pregnancy stage

and classifier (for BCS and LAME); **h** is a vector of random herd-test-day effects; **pe** is a vector of random permanent environmental effects; **a** is a vector of random animal additive genetic effects; **e** is a vector of random residuals; and **X**, **Z_h**, **Z_{pe}**, and **Z_a** are the corresponding incidence matrices.

Seasons were formed by combining three consecutive months (January-March, April-June, July-September and October-December). Parity had three classes with 1, 2 and 3+. Calving age classes were formed for each of the first two parities. Age at first calving had six classes, in which <26 and >34 months were the first and last class, respectively, and other classes were two month classes. Age at second calving was grouped into six classes, in which <39 months was the first class, >47 months was the last class, and other classes were two month classes. For older cows age-parity classes were parity 3. Lactation stage was defined in classes, with each month after calving representing a single class (1 = 5-30 DIM, 2 = 31-60 DIM, ..., 11 = 301-330, 12 = 331-365 DIM). Pregnancy stage was defined in 8 classes as 1 = not pregnant, 2 = 1-90 d, 3 = 91-120 d, 4 = 121-150, 5 = 151-180 d, 6 = 181-210 d, 7 = 211-240 d, 8 = ≥241 d.

Random effects were assumed to be normally distributed with means equals to zero and covariance structure in the bivariate analyses was equal to:

$$\text{Var} \begin{bmatrix} h \\ a \\ pe \\ e \end{bmatrix} = \begin{bmatrix} H_0 \otimes I & 0 & 0 & 0 \\ & G_0 \otimes A & 0 & 0 \\ & & PE_0 \otimes I & 0 \\ \text{symm.} & & & R_0 \otimes I \end{bmatrix},$$

where **H₀** is the (co)variance (2x2) matrix for herd-test-day effects; **G₀** is the genetic (co)variance (2x2) matrix; **PE₀** is the permanent environmental (co)variance (2x2) matrix, **R₀** is the residual (co)variance (2x2) matrix, **I** and **A** are identity and additive relationship matrices, respectively, and $\otimes$ is the Kronecker product.

2.5.4 Results and discussion

2.5.4.1 Phenotypic Description

Figure 1D shows the mean values for ECM, BW, DMI, INEL, ECM/BW^{0.75}, ECM/DMI, LE/INEL and BCS during the lactation for the three Austrian breeds. Holstein cows had the highest milk yield, DMI, INEL and efficiency and the lowest BCS during lactation. Body weight and BCS was highest in Fleckvieh. Brown Swiss had the lowest frequency of lame cows (Table 2D). Figure 2D shows the percentage of normal and lame cows at each stage of lactation. The percentage of lame cows was consistent over the lactation.

2.5.4.2 Genetic Parameters

Heritabilities and repeatabilities for the analyzed traits for Fleckvieh, Brown Swiss and Holstein are shown in Table 3D. For Fleckvieh, the heritability estimates of the efficiency (related) traits ranged from 0.11 for LE/INEL to 0.44 for BW. Heritabilities for BCS and LAME were 0.19 and 0.07, respectively. High repeatabilities in the range of 0.30 for LE/INEL to 0.83 for BW were obtained. For Brown Swiss and Holstein, heritabilities were generally lower, except for BCS. However, as less records were available for these breeds, standard errors were slightly higher, and therefore heritabilities were estimated with greater uncertainty. Repeatabilities were in the same range as

for Fleckvieh. The low heritability estimates for ECM of 0.12, 0.08 and 0.09 for Fleckvieh, Brown Swiss and Holstein, respectively, could be due to the fact that larger and better farms with regard to milk production participated in the project, which maybe decreased genetic variability. Manzanilla Pech et al. (2014) estimated a similar heritability for BW (0.38) for first parity Dutch Holstein cows but significantly higher estimates for fat- and protein-corrected milk (0.46) and DMI (0.46) over the whole lactation based on a multivariate random regression model. Li et al. (2016) reported heritability estimates for DMI in the range of 0.20 to 0.40 in Holsteins, 0.25 to 0.41 in Nordic Red, and 0.17 to 0.42 in Jerseys within the first 24 lactation weeks. Hurley et al. (2017) investigated several ratio-based efficiency traits and found heritabilities in the range of 0.06 to 0.33. Heritabilities for BCS were in the range of literature values with estimates ranging from 0.15 to 0.64 (Dal Zotto et al. 2007; Vallimont et al. 2010; Kougiumtzis et al. 2014). Weber et al. (2013) defined lameness as a binary trait (0=lameness score of 1 or 2, 1=lameness score of ≥ 3) and found a heritability of 0.08 based on a linear model.

2.5.4.3 Genetic Correlations

Genetic correlations between traits are given in Tables 4D, 5D and 6D for Fleckvieh, Brown Swiss and Holstein, respectively.

Efficiency (Related) Traits. For the three Austrian breeds, weak negative genetic correlations were obtained between ECM and BW. Genetic correlations close to zero between BW at different stages of lactation and total lactation milk production were also reported by Berry et al. (2003). In a more recent study, Manzanilla Pech et al. (2014) reported slightly negative genetic correlations between fat- and protein-corrected milk and BW in early lactation and at the end of the lactation.

Genetic correlations near unity were found between DMI and INEL. Also $ECM/BW^{0.75}$, ECM/DMI and $LE/INEL$ were strongly correlated with genetic correlation estimates over 0.92. Moderate genetic correlations were found between DMI and ECM as well as BW in the range of 0.35 to 0.66. Manzanilla Pech et al. (2014) obtained similar genetic correlations over the whole lactation based on experimental research data, with estimates of 0.86 between DMI and fat- and protein-corrected milk yield and 0.45 between DMI and BW.

The three efficiency traits $ECM/BW^{0.75}$, ECM/DMI and $LE/INEL$ were strongly positively correlated with milk yield, negatively correlated with BW, and positively correlated with DMI and INEL, which confirmed the results obtained by Vallimont et al. (2011). The selection for higher milk yield and lower BW will increase feed efficiency.

Body Condition Score. Negative genetic correlations were found between BCS and ECM, $ECM/BW^{0.75}$, ECM/DMI and $LE/INEL$ in the three Austrian breeds, which highlights that more efficient cows have a lower BCS during lactation. In a preliminary study in Austrian Fleckvieh, a low BCS during lactation was associated with a longer calving interval and higher disease rates of metabolic diseases, fertility diseases, mastitis and claw diseases (Köck et al. 2017). Numerous previous studies showed the link between low BCS during lactation and increased fertility and health problems in Brown Swiss (Dal Zotto et al. 2007) and Holstein cows (Dechow et al. 2004; Koeck et al. 2012). High negative genetic correlations between BCS and efficiency traits in the range of -0.64 to -0.70 were also reported by Vallimont et al. (2011). These authors expressed concerns that failure to account for body tissue mobilization will identify cows as efficient that lose more BCS at the beginning of the lactation. Such selection would not improve efficiency as

cow health and fertility would be compromised. Therefore, also the additional information of BCS, fertility and health is needed by selecting for higher efficiency.

Body condition score was moderately correlated with BW, with estimates of 0.46, 0.56 and 0.51 for Fleckvieh, Brown Swiss and Holstein, respectively, which is in agreement with previous studies. Vallimont et al. (2010) reported a genetic correlation of 0.50 between BCS and BW in Holstein cows.

Lameness. Genetic correlations between LAME and the other traits revealed moderate positive genetic correlations between BW and LAME, indicating that animals that are heavier are more prone to lameness. Interestingly, genetic correlations between LAME and the efficiency traits $ECM/BW^{0.75}$, ECM/DMI and $LE/INEL$ were favorable in Fleckvieh and Brown Swiss, suggesting that more efficient cows have less lameness problems. The genetic correlation estimates between BCS and LAME were not significantly different from zero. Genetic correlation estimates involving LAME were associated with large standard errors. Therefore EBV were estimated for ECM, BW, DMI, $LE/INEL$ and BCS and the distribution of the LAME scores were compared from the top and bottom 10% cows ranked by their respective EBV (Table 7D). A low EBV for BW was associated with fewer mildly lameness cases especially in Fleckvieh. In contrast, Brown Swiss and Holstein cows with a low EBV for BW had an increased incidence of moderately lame and lame cases, which was not visible in the genetic correlation estimates. The reason for this finding seems to be the positive correlation between BW and BCS. By selecting for a lower BW also BCS is decreasing, which is especially undesirable in breeds with a lower BCS. Also, Frigo et al. (2010) found that heavier body weight and less body weight change in Holsteins during the first 120 DIM were associated with lower incidences of ketosis, metabolic diseases, infectious diseases, and other diseases.

A high EBV for DMI was associated with a lower incidence of lame cows. Norring et al. (2014) also observed that cows with more severe lameness spent less time feeding per day. Worsening of gait was associated with lower silage intake and less time spent feeding even before severe lameness was scored.

Confirming the genetic correlation estimates, more efficient animals have slightly less lameness problems in all three breeds. Possible reasons could be the lower BW (especially in Fleckvieh) and higher DMI of the more efficient cows. A low EBV for BCS was associated with a higher frequency of lameness. Also, Kougioumtzis et al. (2014) found statistically significant genetic correlations for first lactation weekly locomotion score and BCS, ranging from -0.31 to -0.65, suggesting that cows genetically predisposed for high BCS have fewer locomotion problems.

2.5.5 Final Remarks

Body Weight. Recent studies from Austria have shown that the highest efficiency of a population is achieved with medium BW (Gruber et al. 2017; Ledinek et al. 2019c). In the current breeding programme BW is not included. However, if BW will be included in future dairy cattle breeding programs, the positive correlation between BW and BCS has to be considered. Figure 3D shows the mean BCS from the top and bottom 10% cows ranked by their EBV for BW for Fleckvieh, Brown Swiss and Holstein. As illustrated, selection for a lower BW results in an undesirable decrease in BCS. For this reason BCS is required as additional information when selecting for a low-

er BW since otherwise no distinction between large animals with low BCS and smaller animals with normal BCS is possible.

Dry Matter Intake. Dry matter intake is not recorded in commercial herds on a large scale. Therefore, in most published studies, the number of DMI records is small and estimates of genetic parameters have large standard errors. In the study of Manzanilla Pech et al. (2014) data from historical nutritional experiments from Holstein cows calving between 1990 and 2011 in the Netherlands was combined and a large data set was created. This resulted in a data set consisting of 30,483 records for DMI on 1,297 first parity cows. In the present study a different approach was chosen. To get information on feed intake on a relatively large number of cows, DMI was estimated according to the model of Gruber et al. (2004). In comparison to recorded DMI data from experimental herds, heritabilities for DMI were generally lower, however genetic correlation estimates between DMI and other traits were similar, which highlights the usefulness of this data.

Overall Efficiency. Efficiency is understood as a combination of already existing traits of milk, beef and functional traits and traits aiming at feed efficiency and health. In the current study efficiency was defined as $ECM/BW^{0.75}$, ECM/DMI and $LE/INEL$. For the whole assessment of efficiency also longevity, fertility and health are important. In a preliminary study in Austrian Fleckvieh, cows with a higher efficiency had a longer calving interval and higher frequencies of fertility disorders (cystic ovaries and silent heat). Higher efficiency was associated with a slightly lower incidence of claw diseases, which was also confirmed in the present study with a lower incidence of lameness. More efficient animals had the lowest culling rates. Overall, it was concluded that cows with a medium efficiency combine both, a high milk performance with good fertility and health (Köck et al. 2017). Also, Vallimont et al. (2013) reported that Holstein cows with higher feed efficiency had greater days open, but remained longer in the herd.

2.5.6 Conclusions

The results from the study showed sufficient genetic variation of the efficiency traits based on field data. As expected, more efficient animals have a higher milk yield. Since the additional energy requirement cannot be fully covered by the increased feed intake, more efficient animals mobilize more body reserves. Partly due to the lower BW (especially in Fleckvieh) and higher DMI, more efficient animals have slightly less lameness problems. When selecting for a lower BW, it is important to note that BCS is required as additional information since otherwise no distinction between large animals with low BCS and smaller animals with normal BCS is possible.

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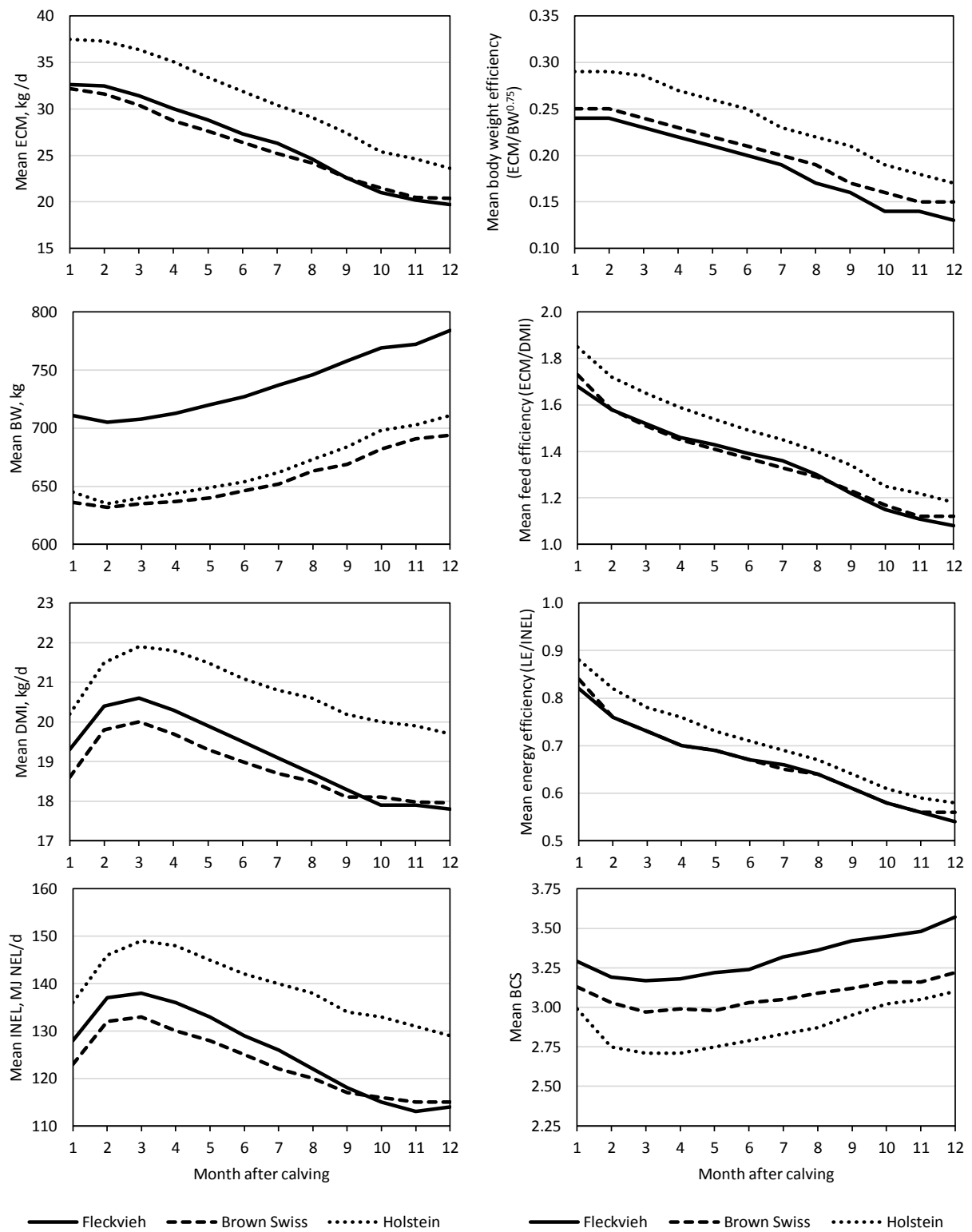


Figure 1D. Mean ECM, BW, DMI, energy intake (INEL), body weight efficiency (ECM/BW^{0.75}), feed efficiency (ECM/DMI), energy efficiency (LE/INEL, LE = energy in milk) and BCS during lactation of Fleckvieh, Brown Swiss and Holstein cows.

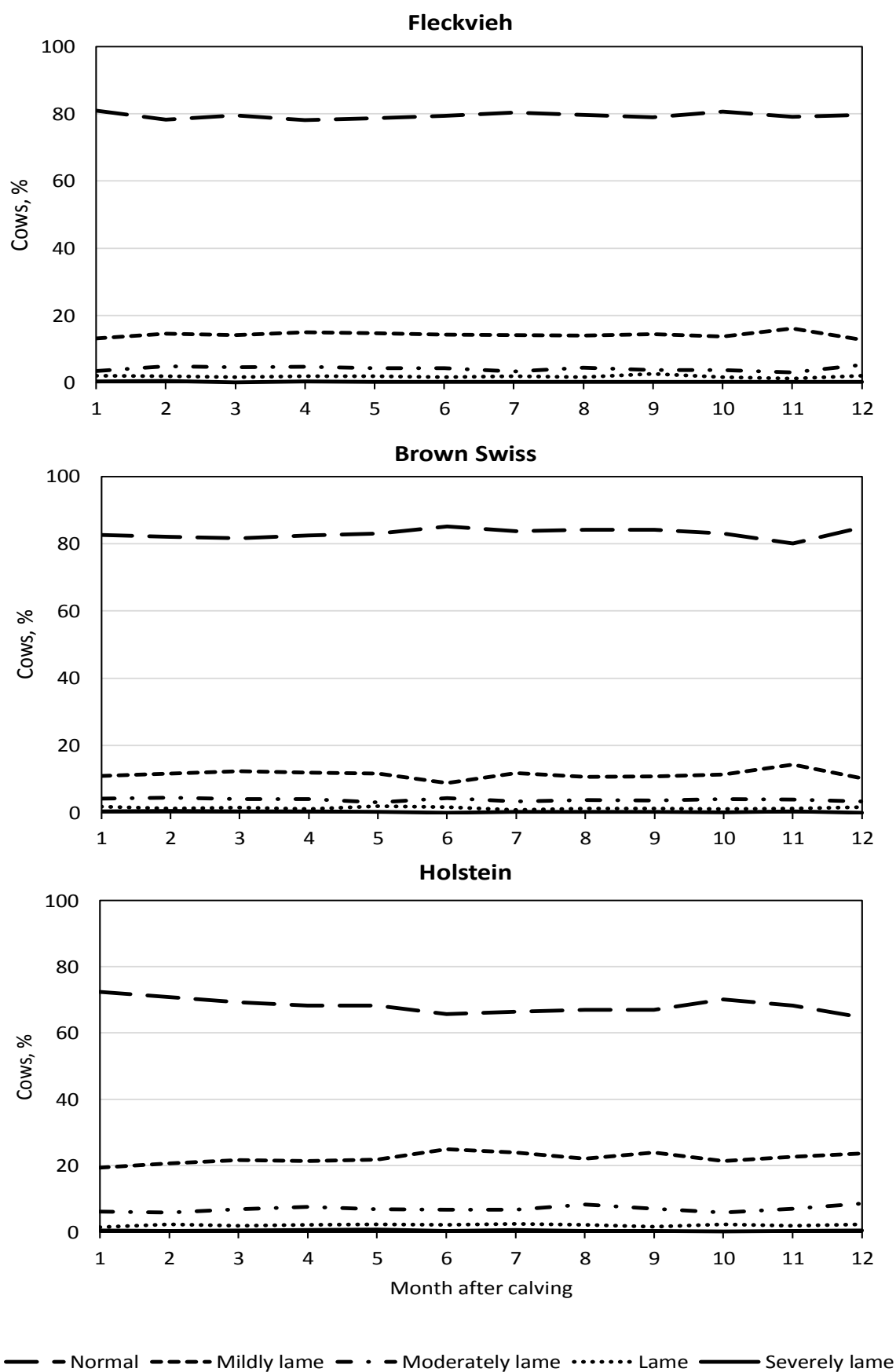


Figure 2D. Percentage (%) of Fleckvieh, Brown Swiss and Holstein cows being recorded as normal, mildly lame, moderately lame, lame and severely lame during lactation.

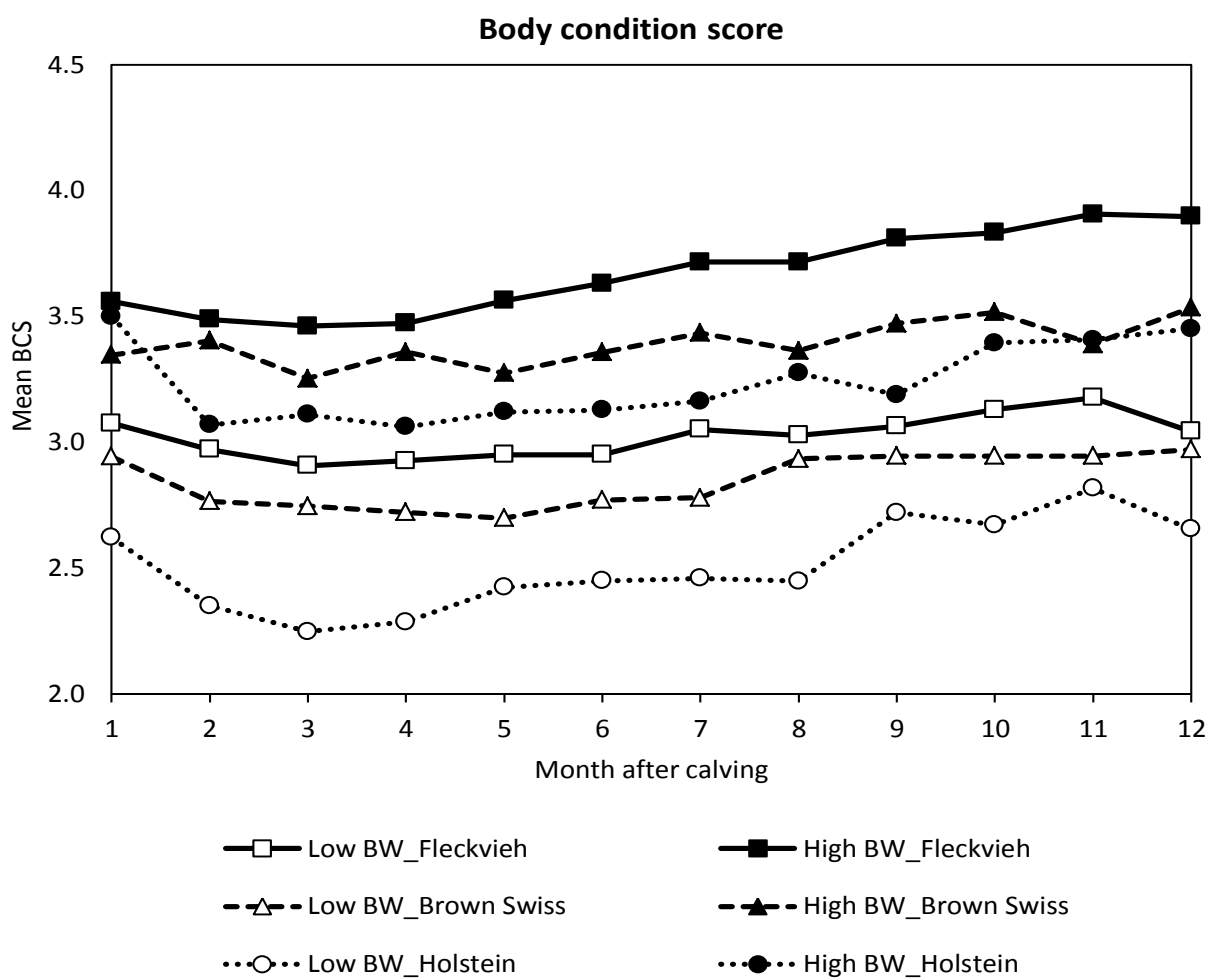


Figure 3D. Mean BCS from the top and bottom 10% of cows ranked by their EBV for BW for Fleckvieh, Brown Swiss and Holstein.

Table 1D. Summary statistics for analyzed traits for Fleckvieh, Brown Swiss and Holstein [ECM, BW, DMI, energy intake (INEL), body weight efficiency (ECM/BW^{0.75}), feed efficiency (ECM/DMI), energy efficiency (LE/INEL, LE = energy in milk), BCS and lameness (LAME)].

	N	Mean	SD	CV (%)
Fleckvieh				
ECM, kg/d	20,945	27.4	8.1	30
BW, kg	20,945	731	85	12
DMI, kg/d	20,945	19.4	2.6	14
INEL, MJ NEL/d	20,945	127.6	21.5	17
ECM/BW ^{0.75}	20,945	0.196	0.057	29
ECM/DMI	20,945	1.39	0.29	21
LE/INEL	20,945	0.680	0.139	20
BCS	20,882	3.29	0.55	17
LAME	20,813	1.29	0.66	51
Brown Swiss				
ECM, kg/d	9,749	26.6	8.2	31
BW, kg	9,749	652	76	12
DMI, kg/d	9,749	18.9	2.6	14
INEL, MJ NEL/d	9,749	124.2	21.3	17
ECM/BW ^{0.75}	9,749	0.207	0.062	30
ECM/DMI	9,749	1.39	0.30	22
LE/INEL	9,749	0.679	0.145	21
BCS	9,459	3.06	0.51	17
LAME	9,739	1.24	0.62	50
Holstein				
ECM, kg/d	7,037	31.8	9.3	29
BW, kg	7,037	662	77	12
DMI, kg/d	7,037	20.9	3.1	15
INEL, MJ NEL/d	7,037	140.3	24.3	17
ECM/BW ^{0.75}	7,037	0.245	0.070	29
ECM/DMI	7,037	1.50	0.31	21
LE/INEL	7,037	0.717	0.146	20
BCS	6,929	2.85	0.64	22
LAME	6,973	1.44	0.75	52

Table 2D. Proportions (%) of different lame score records for Fleckvieh, Brown Swiss and Holstein.

	Number of records	Normal %	Mildly lame %	Moderat. lame %	Lame %	Severely lame %
Fleckvieh	20,813	79.3	14.3	4.2	1.9	0.3
Brown Swiss	9,739	83.0	11.4	3.9	1.4	0.3
Holstein	6,973	68.4	22.2	6.9	2.1	0.4

Table 3D. Heritabilities (h^2 , standard errors in brackets) and repeatabilities (r) for ECM, BW, DMI, energy intake (INEL), body weight efficiency (ECM/BW^{0.75}), feed efficiency (ECM/DMI), energy efficiency (LE/INEL, LE = energy in milk), BCS and lameness (LAME) for Fleckvieh, Brown Swiss and Holstein.

	Fleckvieh		Brown Swiss		Holstein	
	h^2	r	h^2	r	h^2	r
ECM	0.12 (0.02)	0.39	0.08 (0.03)	0.41	0.09 (0.04)	0.48
BW	0.44 (0.05)	0.83	0.38 (0.07)	0.79	0.31 (0.07)	0.80
DMI	0.18 (0.03)	0.45	0.10 (0.03)	0.48	0.08 (0.04)	0.51
INEL	0.13 (0.02)	0.36	0.07 (0.03)	0.40	0.07 (0.03)	0.42
ECM/BW ^{0.75}	0.17 (0.03)	0.44	0.12 (0.03)	0.43	0.14 (0.05)	0.51
ECM/DMI	0.18 (0.03)	0.45	0.10 (0.03)	0.34	0.12 (0.04)	0.41
LE/INEL	0.11 (0.02)	0.30	0.09 (0.03)	0.30	0.11 (0.04)	0.36
BCS	0.19 (0.03)	0.56	0.23 (0.05)	0.60	0.28 (0.06)	0.65
LAME	0.07 (0.02)	0.34	0.04 (0.02)	0.35	0.05 (0.03)	0.34

Table 4D. Genetic correlations between ECM, BW, DMI, energy intake (INEL), body weight efficiency (ECM/BW^{0.75}), feed efficiency (ECM/DMI), energy efficiency (LE/INEL, LE = energy in milk), BCS and lameness (LAME) for Fleckvieh.

	BW	DMI	INEL	ECM/BW ^{0.75}	ECM/DMI	LE/INEL	BCS	LAME
ECM	-0.23 (0.11)	0.65 (0.07)	0.70 (0.06)	0.88 (0.03)	0.89 (0.02)	0.89 (0.03)	-0.45 (0.11)	-0.09 (0.17)
BW		0.50 (0.07)	0.41 (0.09)	-0.67 (0.06)	-0.57 (0.08)	-0.55 (0.08)	0.46 (0.08)	0.61 (0.13)
DMI			0.99 (0.002)	0.25 (0.10)	0.23 (0.11)	0.22 (0.11)	-0.04 (0.12)	0.16 (0.15)
INEL				0.35 (0.10)	0.30 (0.11)	0.29 (0.11)	-0.10 (0.12)	0.10 (0.16)
ECM/BW ^{0.75}					0.97 (0.01)	0.96 (0.01)	-0.60 (0.09)	-0.36 (0.15)
ECM/DMI						0.99 (0.001)	-0.56 (0.09)	-0.22 (0.16)
LE/INEL							-0.54 (0.10)	-0.22 (0.16)
BCS								0.13 (0.16)

Table 5D. Genetic correlations between ECM, BW, DMI, energy intake (INEL), body weight efficiency (ECM/BW^{0.75}), feed efficiency (ECM/DMI), energy efficiency (LE/INEL, LE = energy in milk), BCS and lameness (LAME) for Brown Swiss.

	BW	DMI	INEL	ECM/BW ^{0.75}	ECM/DMI	LE/INEL	BCS	LAME
ECM	-0.15 (0.19)	0.49 (0.16)	0.54 (0.16)	0.83 (0.06)	0.88 (0.04)	0.88 (0.05)	-0.13 (0.20)	-0.40 (0.27)
BW		0.66 (0.11)	0.58 (0.14)	-0.66 (0.12)	-0.53 (0.14)	-0.53 (0.14)	0.56 (0.10)	0.71 (0.26)
DMI			0.99 (0.004)	0.01 (0.21)	0.03 (0.21)	0.00 (0.21)	0.41 (0.18)	0.08 (0.32)
INEL				0.09 (0.21)	0.10 (0.21)	0.07 (0.22)	0.35 (0.19)	0.03 (0.33)
ECM/BW ^{0.75}					0.96 (0.02)	0.95 (0.02)	-0.44 (0.15)	-0.60 (0.24)
ECM/DMI						0.99 (0.001)	-0.37 (0.17)	-0.56 (0.25)
LE/INEL							-0.36 (0.17)	-0.58 (0.25)
BCS								0.83 (0.43)

Table 6D. Genetic correlations between ECM, BW, DMI, energy intake (INEL), body weight efficiency (ECM/BW^{0.75}), feed efficiency (ECM/DMI), energy efficiency (LE/INEL, LE = energy in milk), BCS and lameness (LAME) for Holstein.

	BW	DMI	INEL	ECM/BW ^{0.75}	ECM/DMI	LE/INEL	BCS	LAME
ECM	-0.12 (0.23)	0.57 (0.18)	0.63 (0.17)	0.87 (0.05)	0.93 (0.04)	0.92 (0.04)	-0.46 (0.20)	0.43 (0.34)
BW		0.35 (0.20)	0.29 (0.21)	-0.60 (0.16)	-0.37 (0.18)	-0.39 (0.19)	0.51 (0.12)	0.81 (0.40)
DMI			n.e.	0.30 (0.23)	0.21 (0.24)	0.18 (0.25)	-0.33 (0.24)	0.80 (0.45)
INEL				0.37 (0.21)	0.28 (0.23)	0.26 (0.24)	-0.39 (0.24)	0.79 (0.45)
ECM/BW ^{0.75}					0.93 (0.03)	0.93 (0.03)	-0.62 (0.14)	0.17 (0.30)
ECM/DMI						0.99 (0.001)	-0.44 (0.16)	0.23 (0.29)
LE/INEL							-0.43 (0.17)	0.18 (0.30)
BCS								-0.09 (0.27)

Table 7D. Distribution of lameness scores from the top and bottom 10% cows ranked by their EBV for ECM, BW, DMI, energy efficiency (LE/INEL, LE = energy in milk, INEL=energy intake) and BCS for Fleckvieh, Brown Swiss and Holstein.

	Fleckvieh		Brown Swiss		Holstein	
	Low ECM	High ECM	Low ECM	High ECM	Low ECM	High ECM
Normal, %	72.2	81.4	78.6	88.2	64.1	71.3
Mildly lame, %	17.7	13.4	13.9	8.6	23.5	23.0
Moderately lame, %	6.2	3.9	5.5	1.9	9.0	4.6
Lame, %	3.6	1.1	1.8	1.0	3.2	1.0
Severely lame, %	0.3	0.2	0.2	0.3	0.2	0.1

	Low BW	High BW	Low BW	High BW	Low BW	High BW
Normal, %	79.5	73.8	78.6	82.5	65.1	68.7
Mildly lame, %	13.0	19.3	12.5	14.6	23.2	23.7
Moderately lame, %	5.3	4.6	6.0	2.4	7.5	5.0
Lame, %	2.0	2.0	2.2	0.5	3.5	1.9
Severely lame, %	0.2	0.3	0.7	0.0	0.7	0.7

	Low DMI	High DMI	Low DMI	High DMI	Low DMI	High DMI
Normal, %	73.8	80.3	74.1	83.9	60.9	71.9
Mildly lame, %	14.4	15.7	14.7	11.9	23.4	23.9
Moderately lame, %	7.5	3.1	7.8	2.5	11.3	3.5
Lame, %	3.8	0.8	2.5	1.3	4.1	0.6
Severely lame, %	0.5	0.1	0.9	0.4	0.3	0.1

	Low LE/INEL	High LE/INEL	Low LE/INEL	High LE/INEL	Low LE/INEL	High LE/INEL
Normal, %	71.1	83.7	79.8	86.6	64.2	72.7
Mildly lame, %	19.1	11.4	13.9	9.5	23.9	20.2
Moderately lame, %	5.8	3.8	4.7	3.1	7.9	5.3
Lame, %	3.6	1.0	1.5	0.8	3.8	1.5
Severely lame, %	0.4	0.1	0.1	0.0	0.2	0.3

	Low BCS	High BCS	Low BCS	High BCS	Low BCS	High BCS
Normal, %	68.5	80.0	64.6	83.4	51.5	69.3
Mildly lame, %	17.7	14.5	21.2	13.0	30.0	22.3
Moderately lame, %	8.7	3.8	9.7	2.4	13.3	6.3
Lame, %	4.4	1.6	3.5	1.0	4.5	1.5
Severely lame, %	0.7	0.1	1.0	0.2	0.7	0.6

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2.6 Body weight prediction using body size measurements in Fleckvieh, Holstein, and Brown Swiss dairy cows in lactation and dry periods

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Body weight prediction using body size measurements in Fleckvieh, Holstein, and Brown Swiss dairy cows in lactation and dry periods

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2.6.1 Abstract

The objective of this study was to predict cows' body weight from body size measurements and other animal data in the lactation and dry periods. During the whole year 2014, 6,306 cows (on 167 commercial Austrian dairy farms) were weighed at each routine performance recording and body size measurements like heart girth (HG), belly girth (BG), and body condition score (BCS) were recorded. Data on linear traits like hip width (HW), stature, and body depth etc. were collected three times a year. Cows belonged to the genotypes Fleckvieh (and Red Holstein crosses), Holstein, and Brown Swiss. Body measurements were tested as single predictors and in multiple regressions according to their prediction accuracy and their correlations to body weight. For validation, data sets were split randomly into independent subsets for estimation and validation. Within the prediction models with a single body measurement, heart girth influenced relationship to body weight most with a lowest root mean square error (RMSE) of 39.0 kg, followed by belly girth (39.3 kg) and hip width (49.9 kg). All other body measurements and BCS resulted in a RMSE higher than 50.0 kg. The model with heart and belly girth (Model_{HG BG}) reduced RMSE to 32.5 kg, and adding HW reduced it further to 30.4 kg (Model_{HG BG HW}). As RMSE and the coefficient of determination improved, genotype-specific regression coefficients for body measurements were introduced in addition to the pooled ones. The most accurate equations, Model_{HG BG} and Model_{HG BG HW}, were validated separately for the lactation and dry periods. Root mean square prediction error (RMSPE) ranged between 36.5 and 37.0 kg (Model_{HG BG HW}, Model_{HG BG}, lactation) and 39.9 and 41.3 kg (Model_{HG BG HW}, Model_{HG BG}, dry period). Accuracy of the predictions was evaluated by decomposing the mean square prediction error (MSPE) into error due to central tendency, error due to regression, and error due to disturbance. On average, 99.6% of the variance between estimated and observed values were caused by disturbance, meaning that predictions were valid and without systematic estimation error. On one hand, this indicates that the chosen traits sufficiently depicted factors influencing body weight. On the other hand, the data set was very heterogeneous and large. To ensure high prediction accuracy, it was necessary to include body girth traits for body weight estimation.

2.6.2 Introduction

There are various reasons for predicting the body weight of dairy cows and a number of different ways to do so. Heinrichs et al. (1992) developed prediction models to facilitate a better understanding of heifer growth or treatments on growth. They regressed body weight based on heart girth, height at withers, hip width, or body length. Enevoldsen and Kristensen (1997) estimated

body weight by combining the before rarely used body measurements hip height, hip width, and body condition score (BCS) and considering other animal-specific information like parity and day in milk (DIM). In the UK, linear conformation traits have previously been used to predict body weight (Koenen and Groen 1998; Coffey et al. 2003) and for management purposes (Coffey et al. 2003). As the database was from the 1990s, Banos and Coffey (2012) updated their prediction model on the phenotypic and genetic level, finally resulting in a combination of stature, chest width, body depth, and angularity. Similarly, Heinrichs et al. (2017) reviewed their previously developed prediction model and found it to be sufficient. Yan et al. (2009) used data from 146 cows of a research herd to predict body weight and empty body composition. Haile-Mariam et al. (2014) predicted body weight from linear conformation traits of 430,000 Australian Holstein (HF) cows and examined the relationship between body weight and production and fitness traits. In recent decades, the scientific importance of body weight has increased due to its connection to feed intake and efficiency traits. Body weight or related traits have been included in the (national) breeding indices of Holstein US, New Zealand, Australia, and spring-calving herds in the UK (VanRaden 2004; Harris et al. 2007; Haile-Mariam et al. 2013; Mike Coffey 2017).

With the exception of the studies by Enevoldsen and Kristensen (1997) and Haile-Mariam et al. (2014), predictions of cow body weight have until now been derived from research herds, and the numbers of cows or observations were mostly low. Due to lack of data, validation had to be made internally by additionally splitting these relatively small data sets. Prediction models based on small data sets tend to be very accurate within this data set, but validity for the whole population can be low. Furthermore, while prediction models including body girth measurements or BCS were more accurate than those based solely on linear traits, no incidence of a routine recording traits other than linear traits could be found in the literature. Another point is that body weight has previously been predicted for lactating cows only, although both body weight and body condition are crucial parameters at the end of gestation and thus during the dry period. The physical constitution at calving and management in the dry period indirectly influences production, health, and fertility in the subsequent lactation (Roche et al. 2009).

The objective of this study was to develop and evaluate body weight prediction models for dairy cows during the whole production cycle. In addition to routinely measured linear traits like stature, body depth, or hip width, BCS and muscle score as well as novel traits like heart and belly girth were investigated to take advantage of their high prediction accuracy.

2.6.3 Materials and methods

2.6.3.1 Data recording and data base

Data obtained were based on a one-year data collection period in 2014 and taken from a total of 3,750 Fleckvieh (FV), 1,056 Holstein-Friesian (HF), and 1,500 Brown Swiss (BS) cows kept on 167 Austrian dairy farms (44,441 recordings). The majority of the cows was milked twice a day in a milking parlor system and kept in free-stall barns. In addition to routine performance recording, the Austrian milk recording organizations weighed both lactating and dry cows using a mobile scale and collected several body measurements. Data were entered in the Austrian central cattle database. The following four body traits were recorded at each routine performance recording (nearly each month, up to 12 times per year): Heart girth (HG) = tape measure, behind shoulder around cow, belly girth (BG) = tape measure, around belly just in front of the udder, body condi-

tion score (BCS) = 5-point system by Edmonson et al. (1989), and muscle score (MUSC) = points 1–10 (1 = poorly to 10 = highly muscled).

The following seven linear traits were measured up to three times per cow with a measuring stick by official classifiers of the Federation of Austrian Cattle Breeders: Stature (ST) = measured from top of the spine in between hips to ground, body length (BL) = distance between withers height and at the top of the spine between the hips, pelvis length (PL) = distance between pin bones and hip bones, body depth (BD) = distance between top of spine and bottom of barrel at last rib – the deepest point, independent of stature, hip width (HW) = distance between hip bones, pin width (PW) = distance between pin bones, and knee width (KW) = distance between the knees. As several different measuring points for defining body width are internationally in common use, hip width, pin width, and knee width were named after their specific anatomic characteristics to avoid any possibility of confusion.

On average, cows weighed 699 kg during lactation, and were approximately 95 kg heavier during the dry period (Tables 1E–2E, Tables S1–S2). Dry cows had a wider heart and belly girth, while other linear body measurements changed only slightly. The data set was characterized by a high variation between animals in body size measurements, body weight, and BCS. Body weight ranged between 400 and 1,088 kg during lactation and between 506 and 1,108 kg during the dry period. Minimum and maximum heart girth were 166 and 257 cm during lactation. Overall stature ranged between 128 and 163 cm. Therefore the body weight prediction models were based on a relatively large data set including a high diversity of individuals.

2.6.3.2 Statistical analysis

The fixed effects of the basic model (Eq. 1) were defined in a series of preliminary tests. In accordance with Banos and Coffey (2012), factors with the highest significant influence on body weight were included.

The classes HF and BS of the fixed effect genotype included cows with 100% HF and BS ancestry. Fleckvieh cows were classified into several groups according to their Red Holstein (RH) gene proportion. This classification was chosen in accordance with the results of Ledinek et al. (2019). The number of classes was reduced for easier handling. In the FV class, the two groups with 100% FV and an average of 6.25% RH ancestry were combined due to a lack of significant differences and included 2,604 cows with $\leq 10\%$ RH genes. In FV×RH_m, the two FV×RH groups with an average of 12.5 and 25% RH genes were combined (> 10 to $\leq 44.5\%$, medium proportion of RH genes, 773 cows). Cows with a high proportion of RH were included in FV×RH_h (FV with $> 44.5\%$ genes, 373 cows). Genotypes were analyzed together to characterize the influence of genotype on body weight, as HF and BS are specialized dairy types and FV is a dual-purpose breed. Additionally, this enables the identification of a possible genotype-specific influence of body measurements on body weight.

The fixed effect physiological stage combined the lactation stage with 13 months each (days in milk (DIM) 1 to 364, 28 days per month), and the dry period with four 2-week stages (days -56 to -1 relative to calving). Preliminary tests had shown that prediction accuracy profited noticeably from combining the lactation and dry periods. The fixed effect of parity consisted of the classes 1, 2, 3+4 and ≥ 5 .

The software package SAS 9.4 (SAS 2015) was used for statistical analysis. The PROC MIXED and the method REML (estimation of variance components) were chosen. The Kenward–Roger method was applied to approximate the denominator degrees of freedom as well as the covariance structure VC, which caused the smallest Akaike information criterion. The following basic model was used for testing body measurements (Eq. 1):

$$Y_{ijklm} = \mu + G_i + P_j + PS_k + \sum b_l \times X_l + F_m + \varepsilon_{ijklm} , \quad (1)$$

where Y_{ijklm} = observed body weight, μ = intercept, G_i = fixed effect of genotype, P_j = fixed effect of parity, PS_k = fixed effect of physiological stage (lactation and dry period), b_l = linear regression on l th body measurement (X_l) summed over all body measurements, and F_m = random effect of farm ($m = 1-167$); ε_{ijklm} = residual. Although various approaches were tested, matrices of models that included the effect of cow were not calculable. But it should be pointed out that estimates and estimation errors were well within the common range as reported in the literature.

First, each body measurement was tested within the basic model as a single predictor in linear and quadratic regressions (Eq. 1). Then, further body measurements were added in multiple linear regressions according to their quality of estimation and their Pearson correlations (r) related to body weight. Similar approaches were chosen in other studies (Yan et al. 2009; Banos and Coffey 2012; Haile-Mariam et al. 2014). The influence of body measurements was evaluated according to the Akaike information criterion, the root mean square error (RMSE), the significance of model parameters, and the impact of model parameters on least squares means (LSMs) and regression coefficients. The two most accurate equations Model_{HG BG} and Model_{HG BG HW} were chosen for validation and used to create the final advanced models (Eq. 2). The dataset of the respective model was therefore randomly split into a single estimation and a single validation subset with 80 and 20% of the data (Tables 1E–2E Model_{HG BG HW}, Tables S1–S2 Model_{HG BG}), respectively, including the lactation and dry periods. Each fifth data record was selected for validation. The data set was sorted by the cows' national identification numbers. This resulted in an even distribution within the classes of fixed effects and prevented any trend within traits. The estimation subset of Model_{HG BG} contained an average of 5.7 measurements per cow and an average of 37.2 cows per farm, ranging between 2 and 115 cows (validation subset: 1.4 measurements; 33.2, 2–100 cows). The average number of measurements per cow was 1.9 and 1.0 in the estimation and validation subset of Model_{HG BG HW}. The mean number of cows per farm was 31.4 (2–84 cows) and 14.5 (1–47 cows) in both subsets. Tables S3–S4 present the number of data records within the classes of the fixed effects of the subsets. The testing of interactions between model parameters identified the strong influence of genotype $\times$ body measurement on body weight as well as a significant improvement of estimation accuracy. To take advantage of this, genotype specific regression coefficients $b_l(G_i)$ were tested stepwise for each body measurement (Eq. 2):

$$Y_{ijklm} = \mu + G_i + P_j + PS_k + \sum b_l \times X_l + \sum b_l(G_i) \times X_l + F_m + \varepsilon_{ijklm} , \quad (2)$$

where $b_l(G_i)$ = linear regression on l th body measurement (X_l) for genotype i summed over all body measurements.

As tested in previous studies (Gruber et al. 2004; Ledinek and Gruber 2015), curves were fitted to the LSMs of the fixed effect of physiological stage separately for the lactation and dry periods.

This enables a continuous estimation of body weight depending on DIM and day relative to calving in the dry period.

2.6.3.3 Methods of testing prediction accuracy

Observed body weight was compared with the predicted body weight in the validation subsets (Tables 1E–2E, Tables S1–S2). The two equations Model_{HG BG} and Model_{HG BG HW} included the fitted curves for the fixed effect of physiological stage. Models were evaluated separately for the lactation and dry periods. The validation was done according to Bibby and Toutenburg (1977). Bibby and Toutenburg (1977) defined three causes of variance in the deviation of observed to predicted values within the mean square prediction error (MSPE): errors caused by central tendency (ECT), errors due to regression (ER), and errors caused by disturbance (ED). ECT is the difference between the observed and the predicted means of body weight and describes a systematic and even under- or overestimation in the whole body weight range. ER is 0, if the regression coefficient of the linear relationship between observed and predicted values is 1. ECT and ER represent systematic errors and are undesirable. The linear correction of the models can reduce ECT and ER to 0, while ED cannot be reduced (Bibby and Toutenburg 1977).

To increase visibility of these possible sources for error, we pictured the predicted values centered around their mean (estimated values minus mean of estimated values) on the x-axis (St-Pierre 2003). The differences between observed and predicted values (residuals) were plotted on the y-axis.

2.6.4 Results and discussion

2.6.4.1 Relationships between body measurements

The accurate prediction of body weight requires body measurements, which can be easily and accurately measured on commercial dairy farms during routine linear scoring, and which enable an accurate prediction. Table 3E shows the Pearson correlations between body measurements separately for the lactation and dry periods. All body measurements correlated positively with body weight. Heart girth and belly girth both had the same and strongest relationship to body weight ($r = 0.82, 0.80$; lactation and dry period), followed by hip width ($r = 0.59, 0.57$), and body depth ($r = 0.52, 0.54$). The correlations of body weight with heart and belly girth are in agreement with earlier studies reporting correlations between 0.81 and 0.88 (Yan et al. 2009; Ledinek and Gruber 2014; Stegellner 2014) Yan et al. (2009) explained this with the strong connection of body girth measurements to BCS, which agrees with the findings in the current study. Enevoldsen and Kristensen (1997) found a significantly stronger correlation between hip width and body weight ($r = 0.72$) obtained from cows on commercial Danish dairy farms.

In the current study, knee width was additionally recorded in the linear description, to examine its influence on body weight due to its stronger relationship to BCS, as shown in previous Austrian studies (Ledinek and Gruber 2014; Stegellner 2014). In these studies, a strong correlation to body weight ranging from 0.60 to 0.77 was observed. The noticeably lower correlation ($r = 0.29$) in the current study indicate the difficulty of finding the correct points for measuring this novel trait. Hip and pin bones were characterized by an abundant fat layer and therefore showed a lower connection to BCS as compared to the knees during lactation. Therefore hip, pin width, and pelvis length were easier to measure. Otto et al. (1991) examined hip width and pelvis length and found only very slightly positive relationships to BCS and to the composition of the

9th to 10th rib tissue. Furthermore, in the previous Austrian studies, classifiers were research technicians and had years of prior experience with recording knee width.

In accordance with other studies (e.g. Enevoldsen and Kristensen 1997; Yan et al. 2009; Ledinek and Gruber 2014), height and length measurements had relatively little influence on body weight as compared to body girth measurements, if they were available. The connection between height measurements and BCS, muscle score, or back fat thickness was also very low or partly negative (Enevoldsen and Kristensen 1997; Ledinek and Gruber 2014). Larger animals tended to have a lower body condition. Similar patterns were found for body length in the current study.

2.6.4.2 Body weight prediction models

Table 4E shows the estimators of the two selected prediction equations Model_{HG BG} and Model_{HG BG HW}. Table 5E includes the *P*-values and the RMSEs. The fitted curves for the fixed effect physiological stage are shown separately for the lactation and dry periods. The prediction models are only applicable from day -56 to -1 relative to calving in the dry period and from DIM 1 to 365 in lactation. Otherwise, the curvature of fitted curves changes outside these limits.

Within the models with a single body measurement, heart girth was found to be the best body weight predictor (RMSE = 39.0 kg), followed by belly girth (39.3 kg), and hip width (49.9 kg). The RMSE of other linear traits increased from 51.9 kg (body depth) to 57.0 kg (knee width). The usefulness of heart girth due to its connection to body size and body condition was previously reported by Heinrichs et al. (1992, 2017) and Yan et al. (2009). Unlike in previous studies by Ledinek and Gruber (2015) and Stegellner (2014), BCS predicted body weight with lower accuracy (RMSE = 53.7 kg). Furthermore, the subjectivity of BCS has to be considered. Ferguson et al. (1994) reported that BCS deviated by 0.25 units in 32.6% and by more than 0.5 units in 9.3% of the scorings when experienced observers scored the same cow. A lower concordance was found with inexperienced observers (Kleiböhmer et al. 1998). Incorrect scorings also affect predicted values noticeably, due to the high regression coefficient (about 60 kg point⁻¹).

The combination of heart and belly girth in Model_{HG BG} reduced the RMSE to 32.5 kg. Including a third body measurement showed Model_{HG BG HW} to be the most accurate model (RMSE = 30.4 kg). The prediction accuracy of multiple regressions without body girth traits was even lower than in the models with heart or belly girth as single predictor. Quadratic effects of body traits did not improve body weight prediction significantly, like in the studies by Yan et al. (2009) and Banos and Coffey (2012). The same was found for more than three body measurements.

Most of the fixed effects genotype, parity, and physiological stage as well as the regression coefficients of all body measurements were significant ($P < 0.001$). Body weight increased degressively with increasing parity and showed the typical simultaneous development of body weight and body measurement of growing animals (Enevoldsen and Kristensen 1997; Yan et al. 2009). The difference between cows in parity 1 and the oldest parity class was very low, with 9.46 kg in Model_{HG BG HW} instead of 88 to 100 kg as reported in other studies (Buckley et al. 2000; Haiger and Knaus 2010; Blöttner et al. 2011; Ledinek and Gruber 2015; Ledinek et al. 2019). This shows the strong influence of the additionally included body measurements on body weight in the statistical model.

In the dry period, the fixed effect physiological stage increased from 4.60 to 17.03 kg in Model_{HG BG HW}. The rising influence can be explained by gestation. During gestation, fetus and fetal membranes themselves regulate nutrient distribution to the conceptus, uterus, and mammary glands. Dairy cows also start replenishing body reserves for the next lactation during the last third of the lactation period (Bauman and Currie 1980). The growing gravid uterus gains weight, especially in the last third of the gestation period, and therefore in the dry period, with an additional weight of 24 kg on the 190th day of gestation and overall 87 kg on the 285th day of gestation. Fetus accounts for 9.4 kg and 49.1 kg of this weight, respectively (Bell et al. 1995).

During lactation, a 4th degree polynomial was necessary to avoid on the one hand the bad fit of the 2nd degree polynomial, and on the other hand to avoid a premature change of curvature in the 3rd degree polynomial within the relevant time period. The curve of Model_{HG BG HW} showed the typical development during lactation, with the lowest body weight at DIM 114. Therefore, cows reached the nadir of body weight later than in the basic model without body measurements, which again highlights the strong relationship between body weight and body measurements. Belly girth increased continuously during lactation, while BCS and heart girth started to increase later in lactation (data not shown). Andrew et al. (1994) found the lowest body energy content in HF cows at DIM 77, but without a significant change of body weight as compared to other stages of lactation. This indicated that body weight and belly girth depended more on feed intake (gut fill), while heart girth and BCS were connected more to mobilization and recovering of body tissue, as shown by the correlation coefficients. The RMSE of the curves fitted to the fixed effect physiological stage was 6.8 kg during the dry period and 1.4 kg during lactation.

The regression coefficient for heart girth was 2.52 kg cm^{-1} in Model_{HG BG HW} and corresponded with the findings of similar models by Stegfellner (2014, 3.69 kg cm^{-1}) and Yan et al. (2009, 3.09 kg cm^{-1}). The regression coefficient of belly girth was 2.9 kg cm^{-1} in the current study. It was higher than previously reported with an average of 1.81, 1.17 and 2.27 kg cm^{-1} (Yan et al. 2009; Stegfellner 2014; Ledinek and Gruber 2015). The influence of hip width in Model_{HG BG HW} is quantified with 4.74 kg cm^{-1} . Enevoldsen and Kristensen (1997) examined hip height, hip width, and BCS for body weight prediction. They included a quadratic effect for hip width depending on the data set and model parameters used.

The strong influence of body measurements based on genotype became particularly apparent during the testing of the interactions between the fixed effects and regression parameters. To take advantage of the lower RMSE, we additionally introduced genotype-specific regression coefficients (Figure 1E). The genotype-specific regression coefficient of heart girth decreased with increasing RH gene proportion in FV to pure HF from approximately 1 to 0 kg cm^{-1} . In contrast, the genotype-specific regression coefficient of belly girth rose from the negative number range to a slightly positive one in the specialized dairy genotypes (HF, BS, FV×RH_h). The continuous change of traits with increasing gene proportion of specialized dairy breeds in dual-purpose breeds was shown in Ledinek et al. (2019). Body weight is a function of skeletal development (body size), body condition, and gut fill, which depends on milk yield (Yan et al. 2009). The FV groups had a higher BCS, which is strongly correlated to body weight. The dairy types HF and BS had a higher feed intake per kilogram body weight. According to Yan et al. (2009), heart girth was more strongly connected to body weight than belly girth and belly girth was more strongly influenced by gut fill. Therefore, heart girth had a higher influence on body weight in FV than the

heart girth of Holstein. In contrast to this, the belly girth of FV had a relatively low influence on the body weight as compared to HF and BS.

2.6.4.3 Validation of prediction models

Figures 2E and 3E show the results of the validation of the two body weight equations Model_{HG BG} and Model_{HG BG HW}. The RMSPE and the coefficient of determination (R^2) of the linear regression of observed body weight on estimated body weight are presented in Table 5E separately for the lactation and dry periods. Table 6E includes the decomposition of the MSPE according to Bibby and Toutenburg (1977) and the regression of the residuals between observed and predicted values on the centered predicted values (St-Pierre 2003).

The additional body measurement hip width improved RMSPE from 37.0 to 36.5 during lactation and from 41.3 to 39.9 kg in the dry period. However, it should be considered that Model_{HG BG HW} is based on a lower number of data records.

The R^2 showed that in the dry period, approximately 80.0% of variance in the observed values were explained by the prediction models. During lactation, 83.5% in Model_{HG BG HW} were explained. Yan et al. (2009) presented a high adjusted R^2 of 91% and a RMSPE of 23.9 kg in their model including heart girth, belly girth, and body length. Similar to the prediction models by Ledinek and Gruber (2015), this high accuracy is the result of data recorded in research herds. Haile-Mariam et al. (2014) validated their body weight prediction model with a 10-fold cross-validation ($R^2 = 47\%$, RMSE = 50 kg). The model included linear traits and BCS, but did not include girth measurements.

The partitioning of the MSPE according to its causes ECT, ER, and ED (Bibby and Toutenburg 1977) demonstrated that on average, 99.6% of the variance was caused randomly (Table 6E). That means that the models predict body weight without systematic over- and underestimation. This was visualized in Figure 2E, which shows the intercept and slope of the relationship between the residuals and the centralized predicted values (St-Pierre 2003). If no systematic error exists, intercept (ECT) and slope (ER) do not differ significantly from 0 and the linear regression is equal to x-axis. The slope of Model_{HG BG} is significant (Table 6E), but with 0.012 kg kg^{-1} of body weight observed, we consider the slope to be negligible. Contrary to this, Figure 3E shows the deviation of observed to predicted body weight using the original data. Ideally, the linear regression is identical to the 45° line. The reasons for the lack of a systematic estimation error are multiple: The model parameters used describe the systematic causes of variance in body weight comprehensively and the large and heterogeneous dataset of overall 6,306 cows facilitated a valid prediction.

2.6.5 Conclusions

The body measurements with the highest correlation to body weight (heart girth, belly girth, hip width, and body depth) were found to be the best predictors. Body weight prediction based on BCS or solely on linear traits was insufficient, especially by using stature and body length. Therefore, the two body weight prediction equations Model_{HG BG} and Model_{HG BG HW} were finally chosen. Curves fitted to the fixed effect physiological stage separately for the lactation and dry periods allow a stepless adaption to DIM or the day before calving. The distribution of the MSPE showed that both models predicted body weight without systematic error. Therefore, the chosen model parameters wholly eliminated systematical deviations between predicted and ob-

served values. Furthermore, the large and heterogeneous data set supports a valid prediction. As body weight is an important trait for both management and breeding, the measurement and use of a combination of both heart girth and belly girth is recommended if the use of scales is impossible.

Data availability. The datasets analyzed during the current study are not publicly available as information contained therein could compromise the privacy of third parties.

Authors contributions. All authors made substantial contributions to the project "Efficient Cow" and manuscript preparation. FS and MM programmed the database for collecting data on-farm. KZ and FS coordinated the data collection. MR, KK and LG supported ML during data processing. ML analyzed the data in close collaboration with LG. ML prepared the manuscript supported by LG and BFW. CED was project manager. BFW, CED and LG advised ML during the project.

Competing interests. The authors declare that they have no conflict of interest.

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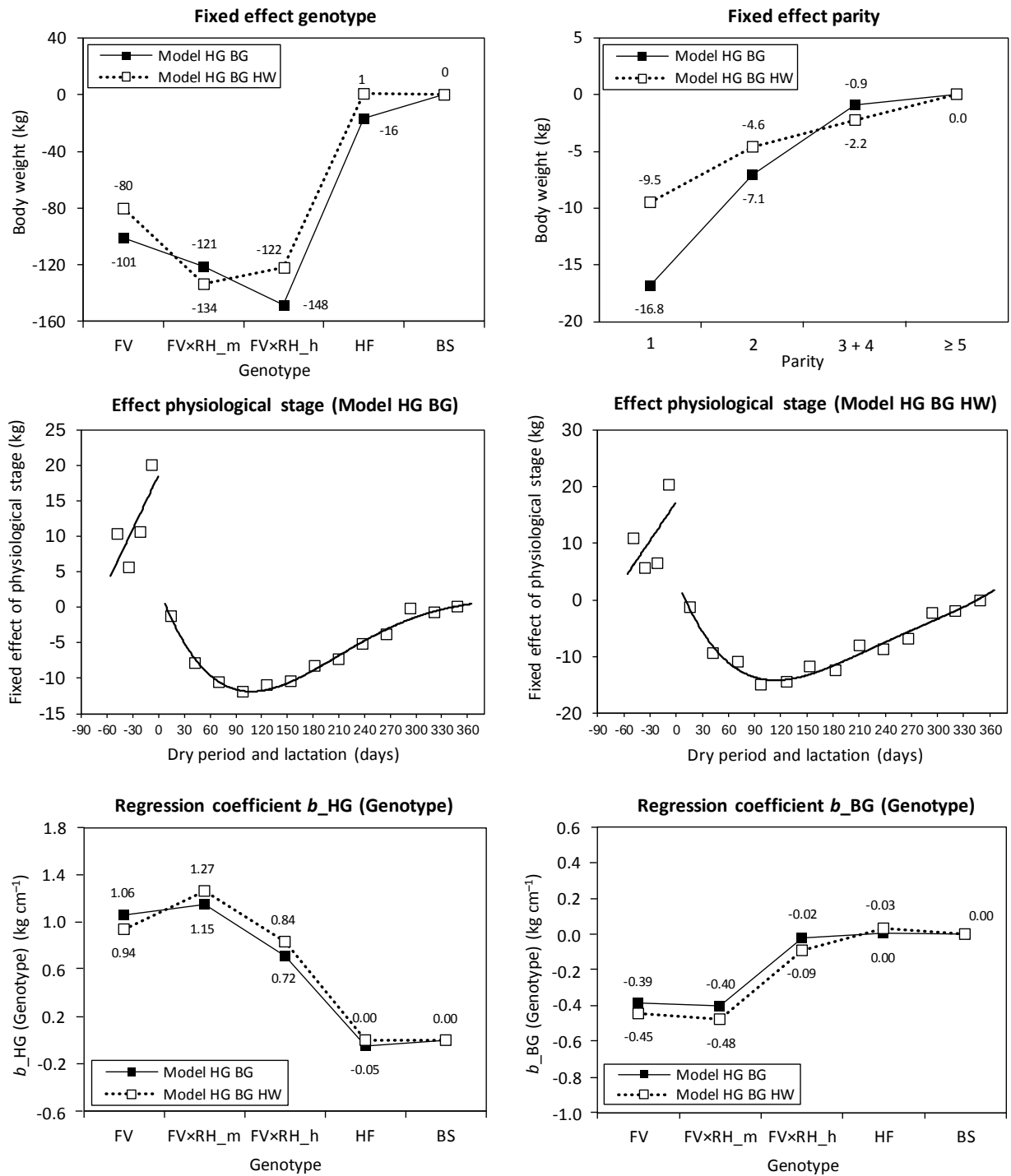


Figure 1E. Fixed effect of genotype (FV = Fleckvieh; RH = Red Holstein (gene proportion); HF = Holstein Friesian; BS = Brown Swiss; m = medium; h = high), parity, the curves fitted on the fixed effect of physiological stage as well as the genotype specific regression coefficients (b) for heart girth (HG) and belly girth (BG) in the prediction equations Model_{HG BG} and Model_{HG BG HW} (HW = hip width).

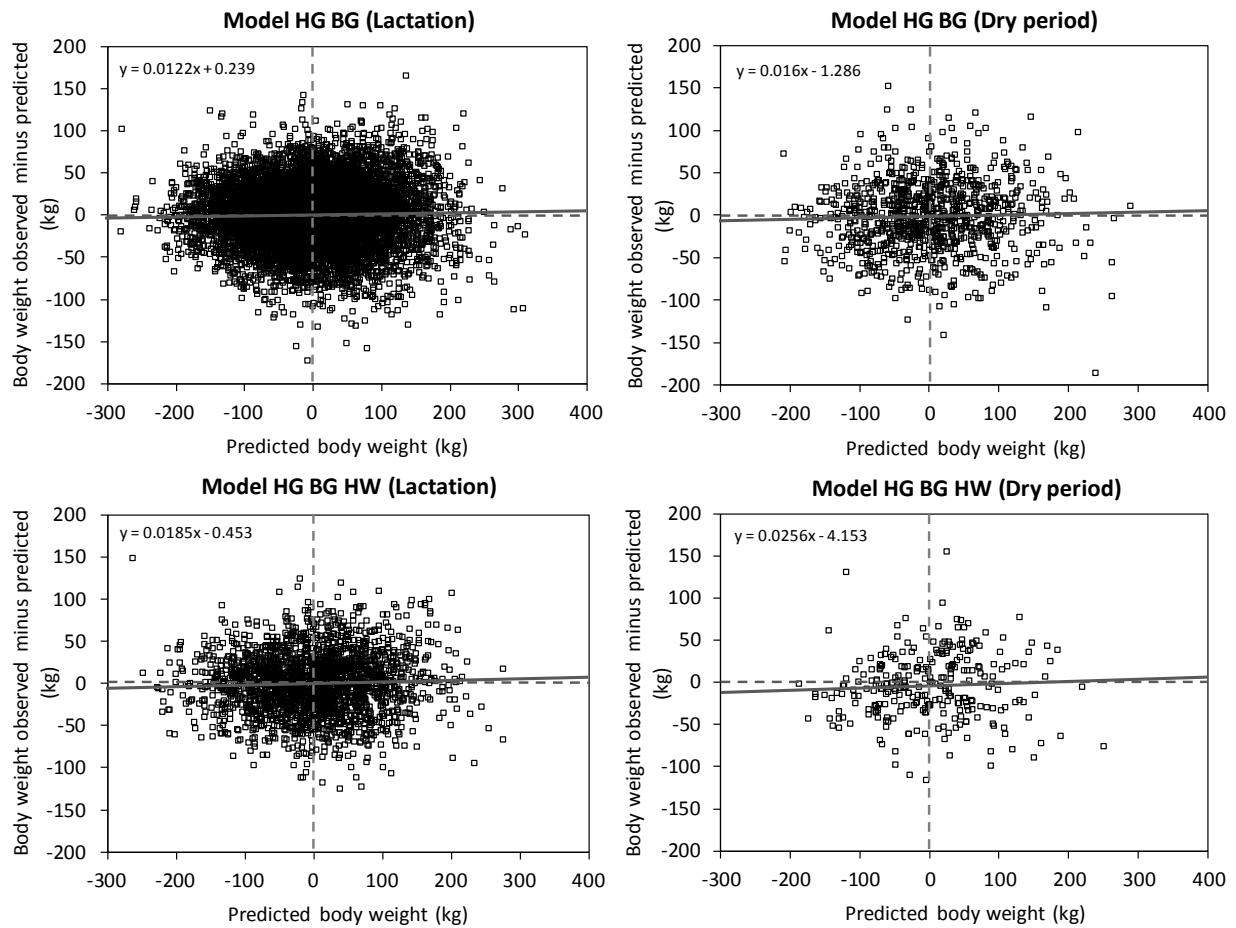


Figure 2E. Decomposition of mean square prediction error (Bibby and Toutenburg 1977) into error of central tendency (ECT, intercept), error of regression (ER, slope) and error of disturbance (ED) shown as centralized residual plot (St-Pierre 2003) of the prediction equations Model_{HG BG} and Model_{HG BG HW} (HG = heart girth; BG = belly girth; HW = hip width).

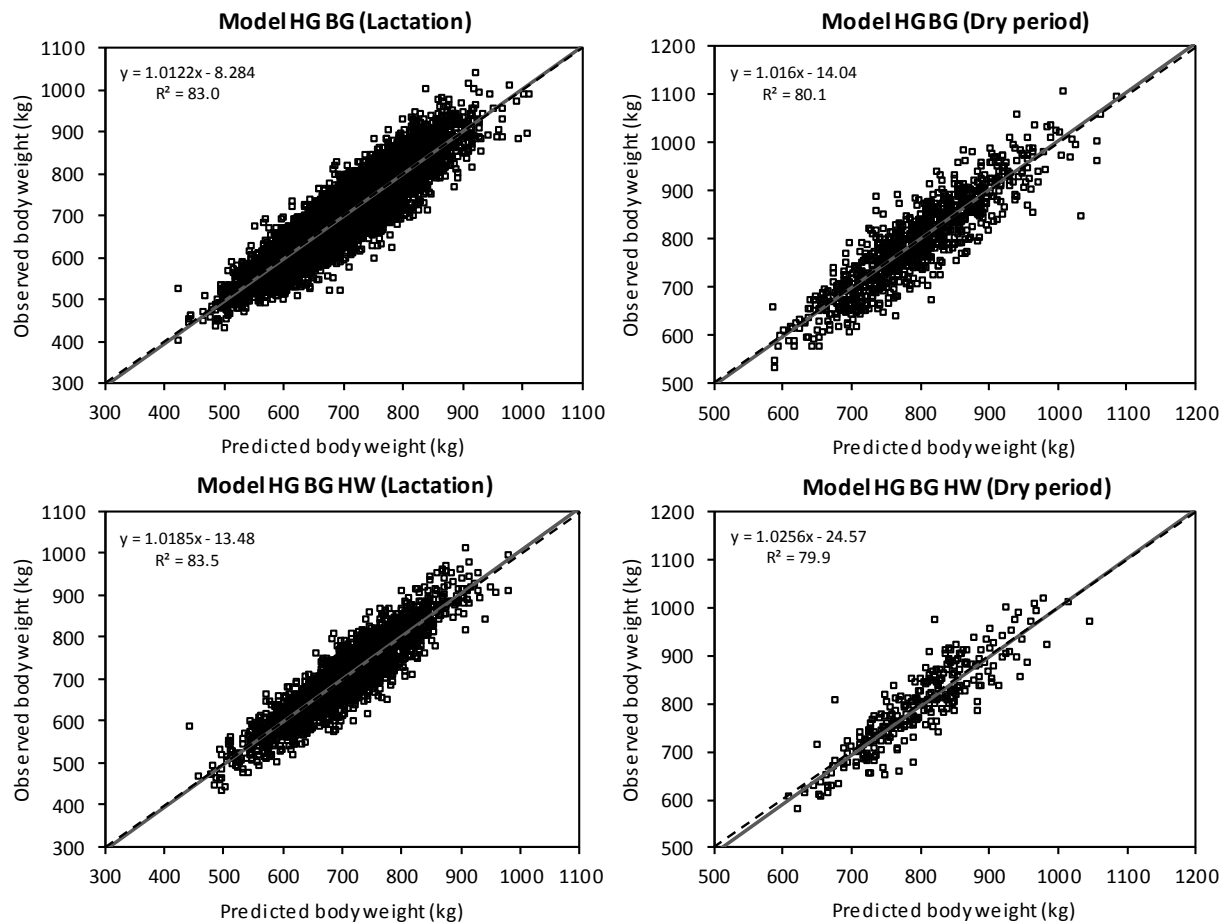


Figure 3E. Linear regression of observed on predicted body weight with original values within the prediction equations Model_{HG BG} and Model_{HG BG HW} (HG = heart girth; BG = belly girth; HW = hip width). If the error of central tendency and regression is 0, then the intercept is 0, the slope is 1, and the regression is identical to the dashed line.

Table 1E. Description of the estimation and validation subset for Model_{HG BG HW} during lactation (HG = heart girth; BG = belly girth; HW = hip width).

Trait	Estimation subset						Validation subset					
	<i>n</i>	Mean	Standard deviation	Variation coefficient	Minimum	Maximum	<i>n</i>	Mean	Standard deviation	Variation coefficient	Minimum	Maximum
Body weight, kg	8,474	702	88.9	12.7	416	1,016	2,080	702	90.1	12.8	435	1,013
Body weight estimated, kg							2,080	702	80.8	11.5	441	980
Heart girth, cm	8,474	210	10.3	4.9	173	253	2,080	210	10.3	4.9	175	247
Belly girth, cm	8,474	256	13.6	5.3	204	312	2,080	256	13.9	5.4	199	298
Stature, cm	8,473	146	4.5	3.1	128	163	2,080	146	4.7	3.2	130	163
Body length, cm	7,947	90	5.6	6.2	73	111	1,969	91	5.6	6.2	74	109
Pelvis length, cm	8,469	56	3.0	5.4	46	68	2,080	56	3.0	5.4	45	66
Body depth, cm	8,471	84	4.5	5.4	67	99	2,077	84	4.5	5.4	69	99
Hip width, cm	8,474	57	3.4	5.9	45	68	2,080	57	3.4	6.0	46	68
Pin width, cm	8,435	39	4.7	12.0	27	59	2,073	39	4.9	12.6	27	59
Knee width, cm	8,427	53	5.5	10.3	36	69	2,072	53	5.6	10.4	34	71
BCS, points 1–5	8,414	3.15	0.58	18.6	1.00	5.00	2,065	3.15	0.57	18.1	1.00	5.00
Muscle score, points 1–10	8,419	5.1	1.5	29.4	1.0	9.0	2,067	5.1	1.5	28.9	1.0	9.0
Parity	8,474	3.0	2.0	65.8	1	13	2,080	3.0	2.0	66.5	1	13
Day relative to calving	8,474	160	96	60	1	364	2,080	164	97	59	1	364

Model_{HG BG} has similar means and standard deviation despite the higher number of animals.

Table 2E. Description of the estimation and validation subset for Model_{HG BG HW} during the dry period (HG = heart girth; BG = belly girth; HW = hip width).

Trait	Estimation subset						Validation subset					
	<i>n</i>	Mean	Standard deviation	Variation coefficient	Minimum	Maximum	<i>n</i>	Mean	Standard deviation	Variation coefficient	Minimum	Maximum
Body weight, kg	909	788	93.6	11.9	528	1,071	262	792	89.0	11.2	578	1,018
Body weight estimated, kg							262	797	77.7	9.7	609	1,046
Heart girth, cm	909	217	11.2	5.1	185	264	262	218	11.0	5.0	190	250
Belly girth, cm	909	271	13.5	5.0	235	307	262	272	13.1	4.8	234	314
Stature, cm	909	146	4.6	3.2	130	163	262	146	4.7	3.2	132	158
Body length, cm	848	91	5.8	6.4	75	109	243	92	5.6	6.1	75	106
Pelvis length, cm	909	56	3.1	5.5	45	66	262	56	2.9	5.1	48	63
Body depth, cm	908	86	4.2	4.8	71	99	262	87	4.4	5.0	75	99
Hip width, cm	909	58	3.4	5.8	47	67	262	58	3.3	5.7	49	70
Pin width, cm	906	40	4.8	12.1	27	57	261	40	5.2	13.0	28	57
Knee width, cm	905	55	6.2	11.2	36	71	261	55	5.8	10.6	38	70
BCS, points 1–5	903	3.57	0.56	15.7	2.00	5.00	262	3.58	0.60	16.8	1.75	5.00
Muscle score, points 1–10	900	5.9	1.6	26.7	1.0	9.0	261	5.9	1.5	25.6	2.0	9.0
Parity	909	2.8	1.8	65.7	1	12	262	2.9	1.7	59.6	1	8
Day relative to calving	909	–26	14	–53	–56	–1	262	–28	14	–49	–56	–1

Model_{HG BG} has similar means and standard deviation despite the higher number of animals.

Table 3E. Pearson correlation coefficients between body weight, body measurements, body condition score (BCS), and muscle score (MUSC), separated for lactation (above diagonal) and dry period (below diagonal).

Trait	BW	HG	BG	ST	BL	PL	BD	HW	PW	KW	BCS	MUSC
BW		0.82	0.82	0.17	0.22	0.41	0.52	0.59	0.43	0.29	0.43	0.46
HG	0.80		0.72	0.25	0.16	0.44	0.55	0.57	0.34	0.21	0.35	0.34
BG	0.80	0.72		0.16	0.25	0.32	0.62	0.54	0.34	0.24	0.30	0.34
ST	0.21	0.25	0.20		0.40	0.50	0.41	0.36	0.04	0.14	0.00 ^{NS}	-0.12
BL	0.15	0.08	0.19	0.43		0.24	0.33	0.32	0.00 ^{NS}	0.05	0.00 ^{NS}	0.01 ^{NS}
PL	0.43	0.40	0.33	0.48	0.23		0.48	0.56	0.23	0.20	0.13	0.02
BD	0.54	0.53	0.60	0.41	0.28	0.46		0.60	0.22	0.24	0.06	0.03
HW	0.57	0.53	0.51	0.34	0.25	0.53	0.54		0.36	0.32	0.16	0.11
PW	0.39	0.29	0.26	0.04 ^{NS}	-0.06 ^{NS}	0.22	0.19	0.36		0.21	0.11	0.22
KW	0.25	0.15	0.22	0.19	0.13	0.18	0.27	0.34	0.18		0.22	0.13
BCS	0.48	0.45	0.39	0.04 ^{NS}	0.05 ^{NS}	0.21	0.21	0.27	0.16	0.23		0.58
MUSC	0.45	0.37	0.35	-0.08	0.10	0.10	0.16	0.20	0.17	0.14	0.49	

^{NS} P -value > 0.05

HG = heart girth; BG = belly girth; ST = stature; BL = body length; PL = pelvis length; BD = body depth; HW = hip width; PW = pin width; KW = knee width; MUSC = muscle score

HG BG and Model HG BG HW.

¹ FV = Fleckvieh with Red Holstein (RH) proportion up to 10.0%; FV×RH_m = FV with medium RH gene proportion > 10.0 to ≤ 44.5%; FV×RH_h = FV with high RH gene proportion > 44.5%; HF = Holstein Friesian; BS = Brown Swiss
² b_{-} = linear regression coefficient
³ select the regression coefficient of the respective genotype in addition to the pooled one (b_{HG} , b_{BG} , b_{HW})
⁴ curve fitted to the fixed effect of physiological stage separately for lactation and dry period

Table 5E. Root mean square error (RMSE), P-values, RMSE of the curves fitted to the fixed effect of physiological stage as well as the root mean square prediction error and the coefficient of determination (R²) of the relationship between predicted and observed body weight.

	Model ¹ _{HG BG}	Model ¹ _{HG BG HW}
Root mean square error, kg	32.5	30.4
P-values		
Genotype	< 0.001	< 0.001
Parity	< 0.001	< 0.001
<i>b</i> _{HG} ²	< 0.001	< 0.001
<i>b</i> _{BG}	< 0.001	< 0.001
<i>b</i> _{HW}		< 0.001
<i>b</i> _{HG} × Genotype	< 0.001	< 0.001
<i>b</i> _{BG} × Genotype	< 0.001	< 0.001
<i>b</i> _{HW} × Genotype		0.119
Physiological stage	< 0.001	< 0.001
RMSE ³ curve physiological stage, kg		
lactating	0.73	1.39
dry	4.96	6.76
Validation		
Root mean square prediction error, kg		
lactating	37.0	36.5
dry	41.3	39.9
R ² observed ⁴ vs. estimated		
lactating	83.0	83.5
dry	80.1	79.9

¹ HG = heart girth; BG = belly girth; HW = hip width

² *b*_— = linear regression coefficient

³ RMSE = root mean square error

⁴ R² = coefficient of determination of the relationship of observed to predicted body weight

Table 6E. Decomposition of root mean square prediction error (Bibby and Toutenburg 1977) as well as the estimators for the regression of the residuals of observed and predicted body weight on the centered predicted body weight (St-Pierre 2003).

Model	<i>n</i> (VAL ¹)	MSPE ²	Variance ³ caused by			Variance ³ (%) caused by			St-Pierre (2003)	
			ECT	ER	ED	ECT	ER	ED	Intercept	Slope
Model including the body measurements heart girth and belly girth (Model _{HG BG})										
lactating	8,013	1,366	0.057	0.963	1,364.5	0.004	0.070	99.925	0.239 ^{NS}	0.0122
dry	872	1,709	1.654	1.704	1,705.7	0.097	0.099	99.804	−1.286 ^{NS}	0.0160 ^{NS}
Model including the body measurements heart girth, belly girth, and hip width (Model _{HG BG HW})										
lactating	2,080	1,331	0.206	2.227	1,328.7	0.015	0.167	99.817	−0.453 ^{NS}	0.0185 ^{NS}
dry	262	1,595	17.25	3.898	1,573.4	1.081	0.244	98.673	−4.153 ^{NS}	0.0256 ^{NS}

¹ VAL = validation

² MSPE = mean square prediction error

³ Bibby and Toutenburg (1977), ECT = error of central tendency; ER = error of regression; ED = error of disturbance

^{NS} *P* > 0.05

2.6.6 References

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Supplement

Table S1. Description of the estimation and validation subset for Model_{HG BG} during lactation (HG = heart girth; BG = belly girth).

Trait	Estimation subset						Validation subset					
	<i>n</i>	Mean	Standard deviation	Variation coefficient	Minimum	Maximum	<i>n</i>	Mean	Standard deviation	Variation coefficient	Minimum	Maximum
Body weight, kg	32,116	699	89.7	12.8	400	1,088	8,013	699	89.6	12.8	403	1,042
Body weight estimated, kg							8,013	699	80.6	11.5	422	1,011
Heart girth, cm	32,116	210	10.4	4.9	166	257	8,013	210	10.3	4.9	168	253
Belly girth, cm	32,116	255	13.9	5.5	193	302	8,013	255	13.9	5.5	204	312
Stature, cm	8,439	146	4.5	3.1	128	163	2,122	146	4.7	3.2	130	163
Body length, cm	7,938	90	5.6	6.2	73	110	1,984	91	5.7	6.3	74	111
Pelvis length, cm	8,436	56	3.0	5.3	46	68	2,121	56	3.0	5.4	45	68
Body depth, cm	8,437	84	4.5	5.4	67	99	2,119	84	4.5	5.4	70	99
Hip width, cm	8,435	57	3.4	5.9	45	68	2,119	57	3.4	6.0	46	67
Pin width, cm	8,425	39	4.8	12.2	27	59	2,122	39	4.6	11.8	28	58
Knee width, cm	8,415	54	5.5	10.3	34	71	2,124	53	5.5	10.2	36	69
BCS, points 1–5	31,944	3.16	0.59	18.7	1.00	5.00	7,971	3.16	0.59	18.7	1.00	5.00
Muscle score, points 1–10	31,919	5.1	1.5	29.8	1.0	9.0	7,968	5.1	1.5	29.6	1.0	9.0
Parity	32,116	3.0	2.0	67.2	1	14	8,013	3.0	2.0	67.3	1	13
Day relative to calving	32,116	159	96	60	1	364	8,013	158	97	61	1	364

Table S2. Description of the estimation and validation subset for Model_{HG BG} during the dry period (HG = heart girth; BG = belly girth).

Trait	Estimation subset						Validation subset					
	<i>n</i>	Mean	Standard deviation	Variation coefficient	Minimum	Maximum	<i>n</i>	Mean	Standard deviation	Variation coefficient	Minimum	Maximum
Body weight, kg	3,440	794	92.1	11.6	506	1,105	872	794	92.3	11.6	534	1,108
Body weight estimated, kg							872	796	81.5	10.2	586	1,085
Heart girth, cm	3,440	218	11.0	5.1	182	264	872	218	10.9	5.0	188	258
Belly girth, cm	3,440	271	13.2	4.9	227	320	872	271	13.6	5.0	231	314
Stature, cm	909	146	4.7	3.2	131	163	264	145	4.4	3.0	130	156
Body length, cm	846	91	5.9	6.4	75	109	246	92	5.4	5.8	75	105
Pelvis length, cm	909	56	3.1	5.4	48	66	264	56	3.1	5.5	45	66
Body depth, cm	908	86	4.2	4.9	71	99	264	86	4.3	5.0	74	99
Hip width, cm	909	58	3.4	5.8	47	68	262	58	3.3	5.8	48	70
Pin width, cm	907	40	4.9	12.4	28	57	261	40	4.7	11.9	27	56
Knee width, cm	907	55	6.0	10.8	36	70	260	55	6.5	11.8	38	71
BCS, points 1–5	3,429	3.61	0.57	15.9	1.50	5.00	871	3.62	0.58	15.9	1.25	5.00
Muscle score, points 1–10	3,423	5.9	1.5	25.1	1.0	9.0	867	5.9	1.5	25.4	2.0	9.0
Parity	3,440	2.8	1.8	65.4	1	13	872	2.8	1.9	67.3	1	12
Day relative to calving	3,440	–24	15	–61	–56	–1	872	–25	15	–58	–56	–1

Table S3. Number of data records of the body weight prediction models Model_{HG BG} and Model_{HG BG HW} separated for lactation and dry period (fixed effect genotype and parity).

DRY-LAC ¹	EST-VAL ²	n	Genotype ³					Parity			
			FV	FV×RH_m	FV×RH_h	HF	BS	1	2	3+4	≥ 5
Model including the body measurements heart girth and belly girth (Model _{HG BG})											
LAC	EST	32,116	13,457	3,860	1,872	5,171	7,756	9,136	7,100	9,120	6,760
LAC	VAL	8,013	3,330	988	478	1,300	1,917	2,290	1,754	2,288	1,681
DRY	EST	3,440	1,506	423	207	502	802	1009	848	1007	576
DRY	VAL	872	402	93	43	121	213	267	201	250	154
Model including the body measurements heart girth, belly girth, and hip width (Model _{HG BG HW})											
LAC	EST	8,474	3,530	1,090	495	1,403	1,956	2,292	1,898	2,503	1,781
LAC	VAL	2,080	867	262	119	351	481	564	487	587	442
DRY	EST	909	370	99	46	158	236	274	236	239	160
DRY	VAL	262	104	33	22	36	67	60	79	72	51

¹DRY = dry period; LAC = lactation; ²EST = data set for estimation; VAL = data set for validation

³FV = Fleckvieh (Red Holstein genes ≤ 10.0%); RH = Red Holstein; HF = Holstein Friesian; m = medium proportion of RH genes (> 10.0 – ≤ 44.5%); h = high proportion of RH genes (> 44.5%); BS = Brown Swiss

Table S4. Number of data records of the body weight prediction models Model_{HG BG} and Model_{HG BG HW} separated for lactation and dry period (fixed effect of physiological stage: lactation and dry period).

DRY-LAC ¹	EST-VAL ²	Dry period (weeks ante partum)				Lactation (months post partum, 28 days per month)												
		7–8	5–6	3–4	1–2	1	2	3	4	5	6	7	8	9	10	11	12	13
Model including the body measurements heart girth and belly girth (Model _{HG BG})																		
LAC	EST					2,950	3,054	2,944	2,909	2,888	2,695	2,765	2,618	2,644	2,587	2,020	1,284	758
LAC	VAL					791	777	690	730	659	732	715	670	644	543	493	346	223
DRY	EST	483	860	1,028	1,069													
DRY	VAL	131	237	272	232													
Model including the body measurements heart girth, belly girth, and hip width (Model _{HG BG HW})																		
LAC	EST					685	844	773	828	760	726	739	662	685	635	553	367	217
LAC	VAL					153	225	185	169	180	180	177	170	158	174	149	109	51
DRY	EST	131	273	290	215													
DRY	VAL	46	75	94	47													

¹DRY = dry period; LAC = lactation; ²EST = data set for estimation; VAL = data set for validation

3 Diskussion und Schlussfolgerungen

3.1 Futteraufnahmevorhersage und Datenerhebung

Die exakte Berechnung von Futter- und Energie-Effizienz setzt die Erhebung der individuellen Futteraufnahme voraus. Dies ist jedoch auf österreichischen Milchviehbetrieben nicht möglich. Daher wurde auf eine möglichst tierindividuelle Schätzung mittels Vorhersagemodell Nr. 1 für separate Kraftfutterergänzung von GRUBER et al. (2004) zurückgegriffen. Erhebung und Dateneingabe der Rationsinformation folgten einem dafür neuentwickelten Codierungssystem der Rationskomponenten (LEDINEK et al. 2016). Jeder Rationskomponente wurde die Art ihrer Verabreichung (Komponententyp) zugeordnet. Dies ist die Voraussetzung für die Berechnung von Kraftfuttermenge und Energiegehalt des Grundfutters im Vorhersagemodell für die Futteraufnahme. Das Vorhersagemodell wurde mittels eigens entwickelten mathematischen Gleichungen an die unterschiedlichen Kombinationen der Komponententypen angepasst. Damit war die Voraussetzung einer korrekten Abbildung von Rationskomponenten und Fütterungssystem erfüllt. Die Kombination der Komponententypen in einer Ration reflektierte gleichzeitig das Fütterungssystem (Haupttypen: reine Grundfutterration, FOR; Grundfutter mit separat gefüttertem Kraftfutter, SEP; aufgewertete Mischration, PMR; Totalmischration, TMR). Diese Art der Codierung erlaubte einen weiterführenden Einblick in die Fütterung österreichischer Milchviehbetriebe (LEDINEK et al. 2016).

Ein weiterer Punkt neben der korrekten Berücksichtigung der Ration war eine möglichst genaue und tierindividuelle Schätzung der Futteraufnahme. Die Validierung von derzeit fünf aktuellen Vorhersagemodellen durch JENSEN et al. (2015) ergab für GRUBER et al. (2004) die valideste Vorhersage verglichen zu den Modellen des NRC (2001), VOLDEN et al. (2011), dem Wageningen-Dairy Cow Model (DCM) (ZOM et al. 2012a,b) und dem TDMI-Index nach HUHTANEN et al. (2011). Die Validierung basiert auf 12 skandinavischen Experimenten mit 917 laktierenden Milchkühen in insgesamt 94 Versuchen. Jerseys, Danisch/Swedish Red in unterschiedlichen Laktationen und Laktationsstadien waren vertreten. Alle Vorhersagemodelle verwenden ähnliche tierspezifische Merkmale. Alle Modelle außer jenes des NRC (2001) berücksichtigen Rationsmerkmale. Das Modell von VOLDEN et al. (2011) gehört zu den semi-mechanistischen Modellen und arbeitet mit einem sogenannten „fill-factor“ System. Dem Fülleffekt des Futters steht die Futteraufnahmekapazität gegenüber. Diese berücksichtigt Lebendmasse, Laktationsstadium, Laktationszahl, Rasse und Milchmenge. Das ähnliche Wageningen-DCM (ZOM et al. 2012a,b) beinhaltet weder Lebendmasse noch Milchmenge. Huhtanen et al. (2011) kombinierten einen Silage-Index (SDMI-Index) mit dem Konzentrat-Index (CDMI-Index). Der SDMI-Index integriert die Grundfutterqualität, der SCMI-Index die Menge und Zusammensetzung des Kraftfutters. Das Modell von GRUBER et al. (2004) unterscheidet sich jedoch deutlich darin, wie die Regressionskoeffizienten von Milchleistung, Lebendmasse und Kraftfuttermenge einfließen. Sie variieren je nach Laktationsstadium (gemessen in Laktationstagen). Dies bildet die Veränderungen im physiologischen Stadium von der Früh- zur Spätlaktation ab, unter anderem jene einer katabolen Stoffwechselsituation zu einer anabolen (KORVER 1982).

3.2 Rationsgestaltung

Tabellen 2A und 3A zeigen die Anzahl der Datensätze, der Kühe und Betriebe nach Grundfuttertyp und Fütterungssystem. Es zeigt also, wie viele Tiere, Betriebe oder Datensätze von einer bestimmten Grundfutterzusammensetzung oder einem bestimmten Fütterungssystem betroffen waren. Aufsummiert ergeben sich höhere Zahlen an Kühen und Betrieben, als im Projekt teilgenommen haben. Dies ist nicht überraschend. So wurden Art und Menge der Kraftfutterfütterung verändert. Damit änderte sich auch das Fütterungssystem. Besonders oft wird eine PMR zur TMR, wenn kein separates Kraftfutter aufgrund geringerer Leistung mehr gefüttert wurde. Dasselbe tritt auch häufig zwischen SEP und FOR auf. Ergab sich für ein Tier aufgrund seiner Leistung eine Kraftfuttergabe, so änderte sich seine Ration individuell von FOR zu SEP. Diese Unterschiede traten im Laufe der Laktation entweder für die gesamte Herde, oder innerhalb eines Erhebungs-termins zwischen Futtergruppen oder Einzeltieren auf, abhängig von Milchleistung oder vorhandenem Futter. Daher beziehen sich alle Analysen auf die tierindividuelle Ebene der Einzelmilchleistungsprüfung. Dies berücksichtigt den Effekt der Fütterung möglichst tierindividuell. Einige wenige Betriebe schufen sich auch im Laufe der Erhebung einen Mischwagen an, oder dieser war defekt. Ähnlich verhält es sich auch für den Grundfuttertyp. Das Futter veränderte sich nach saisonalem Angebot (z. B. Weide, Alpung oder günstiger Zukauf von Luzerne oder Maissilage). Damit zeigt sich eine große Vielfalt der Fütterung auf Praxisbetrieben.

Tabelle 1 suppl. zeigt die Verteilung der Grundfuttertypen innerhalb der Fütterungssysteme. Reine Grundfutterrationen gehörten zumeist grünfutter-, grassilage- oder heubetonen Rationen an. Allerdings gab es auch ungewöhnliche Kombinationen einzelner Betriebe wie z. B. Weidehaltung ergänzt mit einer TMR im Stall für Kühe in der Spätlaktation.

Die Genotypen verteilten sich über alle Fütterungssysteme und Haupt-Grundfuttertypen (Tabelle 4A, 2 suppl.). Einerseits zeigte sich eine Aufteilung in Dauergrünland- und maisanbaufähige Gebiete. Andererseits ließen sich auch die typischen Schwerpunkte der Fütterung und die regionale Rasseverteilung nach Genotyp erkennen (ZAR 2016). So waren luzerne-betonte Rationen für Brown Swiss (BS) die Ausnahme.

3.2.1 Rationszusammensetzung nach Grundfuttertyp

Abbildung 1A.a zeigt die Grundfutterzusammensetzung der 18 Grundfuttertypen. Botanische Zusammensetzung und Konservierungsform variierten deutlich aufgrund der in Österreich unterschiedlichen klimatischen Bedingungen. Trotzdem zeigte sich eine eindeutige Aufteilung in zwei vorherrschende Kategorien: beinahe reine Grassilagerationen (Typ GS, 82 % Grassilage, 39,5 % aller Datensätze) und Typ MS mit 49 % Maissilage und 42 % Grassilage (27,1 % aller Datensätze). Obwohl klee- und luzerne-betonte Rationen nur 8,5 und 2,6 % aller Datensätze ausmachten, ersetzte der Leguminosenanbau regional das Dauergrünland. Heubetonte Rationen (56,5 % Heu) betrafen 8,1 % aller Datensätze. Die ebenfalls geringe Nutzung an grünfutterbetonten Rationen bzw. Weide (5,6 % der Datensätze) hat zwei Gründe: Einerseits ist die Weidehaltung durch klimatische und topografische Bedingungen eingeschränkter als z. B. in Irland und Neuseeland (DILLON et al. 1995, HARRIS und KOLVER 2001). Andererseits ist ein Rückgang der Weide durch vermehrte Stallfütterung und Leistungssteigerung in den letzten Jahrzehnten erkennbar (KNAUS 2009, 2016).

3.2.2 Rationszusammensetzung nach Fütterungssystem

Abbildung 1A.b zeigt die Grundfutterzusammensetzung nach Fütterungssystem. Reine Grundfütterationen (FOR) enthalten einen hohen Anteil an Weide und Heu. Weide und Heu traten kombiniert mit Mischrationen kaum auf. Heu diente oft als Lockfutter oder als Strukturkomponente. Der Anteil an Gras- und Maissilage stieg mit der intensiveren Fütterung von FOR über SEP zu den Mischrationen (60 % Grassilage und 30 % Maissilage) an. Trotzdem dominierte das Dauergrünland mit 62 % am Grundfutter in der TMR und 84 % des Grundfutters in FOR. Jene betrafen nur 2,4 % aller Datensätze. Der Kraftfutteranteil lag bei SEP, PMR und TMR bei 27, 35 und 30 %. Die tierindividuelle Anpassung der Kraftfuttermenge dominierte mit 85,7 % der Datensätze (42,8 % SEP, 42,9 % PMR). Insgesamt zeigten der Kraftfutteranteil und der hohe Grad der Mechanisierung (Kraftfutterstation, Transponder, Mischwagen usw., Daten nicht gezeigt), sowie der geringe Anteil reiner Grundfütterationen ohne Kraftfutter, dass das Produktionsniveau der Projektbetriebe überdurchschnittlich war. Damit befanden sich die Projektbetriebe im überdurchschnittlichen Bereich des seit Jahrzehnten beobachteten Strukturwandels (BMLFUW 2016).

3.3 Nährstoffaufnahme, Effizienz und Energieversorgung

Der Genotyp beeinflusste alle Merkmale mit $p < 0,001$. Die Milchleistung, die Futter- und Nährstoffaufnahme sowie der Kraftfutteranteil stiegen mit steigender Milchbetonung von Fleckvieh (FV) zu Holstein (HF) mit zunehmendem Red Holstein-(RH)-Anteil an (Tabelle 5A, LEDINEK et al. 2019a). Lebendmasse und besonders der BCS nahmen jedoch ab. Die FV-Gruppen bis FV×RH12.5 sind einander biologisch besonders ähnlich. BS bewegte sich im Bereich von FV bis FV×RH25. Sie waren jedoch etwas leichter als HF. Ihr BCS lag ungefähr in der Mitte von FV und HF. Ähnliche Muster eines höheren Energiegehalts und Kraftfutteranteils bei Rassen mit stärkerer Betonung der Milchleistung entsprechen den Ergebnissen zahlreicher Studien (z. B. DILLON et al. 2003).

In der vorliegenden Studie produzierten FV und BS 12 % mehr Milch als der Durchschnitt der Kontrollkühe dieser Rassen im Jahr 2015. HF gab dagegen nur um 5 % mehr Milch (ZAR 2016). Daher sind die Rassen einander ähnlicher als im österreichischen Durchschnitt. Der Milcheiweißgehalt sank wenig überraschend mit steigendem RH-Anteil von FV-Gruppen bis FV×RH25 zu HF. Der Milcheiweißgehalt von BS entsprach dessen züchterischen Betonung (ZAR 2016). Bezüglich Milchfettgehalt zeigte sich kein Trend von FV bis HF. Allerdings hatten BS und HF den geringsten Milchfettgehalt (Tabelle 1B, LEDINEK et al. 2019b). In früheren Studien wiesen HF geringere Milchinhaltsstoffgehalte verglichen mit Rassen geringerer Milchbetonung auf (DILLON et al. 2003). Auch neuseeländische HF-Typen hatten höhere Milchfett- und Milcheiweißgehalte als HF US-amerikanischer Abstammung. KENNEDY et al. (2003) beschreiben den gleichen Trend zwischen Kühen einer Rasse mit niedrigerem und hohem Zuchtwert für die Milchleistung. Dieser Effekt begründet sich auf ein größeres Verhältnis von Wachstumshormon zu Insulin und einem insgesamt höheren Wachstumshormongehalt im Blut von hochleistenden Kühen während der Laktation (HART et al. 1978, HART et al. 1979).

Alle Effizienzmerkmale zeichneten sich durch einen ansteigenden Trend von FV zu HF mit zunehmendem RH-Anteil aus (Abbildung 1B). Die Lebendmasse-Effizienz stieg aufgrund der zunehmenden Milchleistung trotz ähnlicher Lebendmasse der FV-Gruppen bis FV×RH25 an. BS wies eine ähnliche Lebendmasse wie HF und eine ähnliche Milchleistung zu FV auf. Daher liegt deren Lebendmasse-Effizienz auch in der Mitte von FV und den effizientesten Gruppen HF und

FV×RH5075. Je geringer der BCS eines Genotyps war, desto effizienter produzierte er Milch. Im Gegensatz dazu entsprachen Futter- und Energie-Effizienz von BS jener von FV. Dies liegt an deren ähnlicher Milchleistung und Futteraufnahme. Kühe oder Genotypen mit stärkerer Milchbetonung weisen nicht nur eine höhere Leistung und Nährstoffaufnahme auf. Sie teilen auch einen größeren Anteil der aufgenommenen Nährstoffe der Milchproduktion als dem Körper zu (YAN et al. 2006). In der aktuellen Studie produzierte HF futter-effizienter als HF-Kühe einer vergleichbaren dänischen Studie (KRISTENSEN et al. 2015). Sie erreichten jedoch nicht die Futter-Effizienz der kleineren und leichteren dänischen Jerseys. Im Gegensatz dazu produzierten die dänischen HF mehr ECM pro kg Lebendmasse als alle Genotypen der aktuellen Studie. Die dänischen HF waren deutlich leichter (dänische HF 602 vs. österreichische HF 662 kg).

In einem Schweizer Rassenvergleich waren neuseeländische und Schweizer HF am effizientesten (PICCAND et al. 2013). Allerdings glichen sich Schweizer FV und Schweizer BS. Das Schweizer FV hatte jedoch einen ähnlichen RH-Anteil wie FV×RH5075. Insgesamt produzierten die Schweizer Kühe weniger effizient Milch als in der aktuellen und dänischen Studie. Das zeigt den Unterschied zwischen High-Input- und weidebasierten Low-Input-Systemen. Weidebasierte Low-Input-Systeme zielen auf eine hohe Produktivität der Fläche und nicht des Einzeltieres ab (DILLON et al. 1995). Die hohe Milchleistung, das Ernährungsniveau und die geringe Nutzung von reinen Grundfuttermitteln oder Weide zeigten das für Österreich überdurchschnittliche Produktionsniveau der Projektbetriebe. In den letzten 50 Jahren fand ein Strukturwandel zu größeren und spezialisierten Einheiten statt. Saisonalität, Weidehaltung und hauptsächlich grundfutterbasierte Fütterung verloren an Bedeutung (KNAUS 2016). Zusätzlich reduziert eine ansteigende Menge an Kraftfutter die Effizienz, mit der Wiederkäuer für die menschliche Ernährung untaugliche Futtermittel in hochwertige Lebensmittel umwandeln. Die Fläche an verwendetem Dauergrünland pro Tonne Milch korrelierte hingegen positiv mit der Lebensmittelkonvertierungs-Effizienz (ERTL et al. 2015). Eine hohe Effizienz durch eine Milchleistungssteigerung setzt, wie auch in der aktuellen Studie gezeigt, einen höheren Kraftfuttereinsatz voraus. Kleinere und leichtere Typen erreichen dieselbe Effizienz mit geringerer Futterqualität (STEINWIDDER 2009).

Die durchschnittliche Energiebilanz (LEDINEK et al. 2019b) bewegte sich zwischen -1,6 (FV×RH12.5) und 3,8 MJ NEL/Tag (BS). Gemeinsam mit der vollständigen Erholung der Körperkondition spricht dieses Ergebnis für eine leistungsgerechte Fütterung auf den Projektbetrieben. Tiere mit hoher Milchleistung sind besonders auf eine hohe Energiedichte der Ration angewiesen, um die verlorenen Fettreserven wieder aufzubauen (COFFEY et al. 2004, YAN et al. 2006). Die Rassen mit der höchsten Milchleistung (HF und FV×RH5075) regenerierten ihren Körper hauptsächlich in der späten Laktation (Abbildung 1B, Tabelle 5 suppl.). In diesem Laktationsabschnitt hatten sie eine relativ geringere Milchleistung verglichen mit den anderen Rassen. Die Energiedichte der Ration war jedoch deutlich höher (Abbildung 2A, Tabelle 7 suppl.). HF verlor am meisten an Körperkondition. Diese stagnierte auch am längsten aller Gruppen auf deren geringstem Niveau bis zum 154. Laktationstag. Die FV-Gruppen mobilisierten weniger Körperfett und regenerierten sich früher. Die Ration von BS war relativ zur Milchleistung energiereich. Daraus folgte auch die geringste Energieeffizienz. BS erreichte einen positiven Energiestatus am 62. Laktationstag. FV folgte am 100. Laktationstag. FV×RH25, HF und FV×RH5075 wiesen erst zwischen dem 110. und 120. Laktationstag eine positive Energiebilanz auf. Damit dauerten die Mobilisationsvorgänge der Genotypen mit der höchsten Effizienz doppelt so lange (Abbildung 1B, Tabelle 8 suppl.).

Der Effekt der Laktationszahl zeigt einen Anstieg der Effizienz bis zur Laktation 3+4 (LEDINEK et al. 2019b). So produzierten Kühe der 3. und 4. Laktation mehr Milch als in der 2., obwohl die vorhergesagte Futteraufnahme pro kg Lebendmasse etwas geringer ausfiel. Der BCS spiegelt diese Entwicklung wider. Erstlaktierende Kühe teilten die Nährstoffe zusätzlich dem Wachstum zu, wie die steigende Lebendmasse zeigte. Ein über die Laktationszahlen ansteigender BCS war hauptsächlich bei den FV-Gruppen zu finden. Die spezialisierten Milchtypen HF und BS verloren Körperkondition von der ersten bis zur höchsten Laktationszahl. Ein Abgleich der BCS-Entwicklung während der Laktation zeigt, dass HF und BS gegen Laktationsende die gleiche Körperkondition wie zu Laktationsbeginn vor dem BCS-Verlust erreichen. Der BCS der FV-Gruppen übertraf jenen zu Laktationsbeginn deutlich. COFFEY et al. (2004) schlussfolgerten daher: Die starke züchterische Betonung der Milchleistung führt zu einer so starken Mobilisation von Körpergewebe in der frühen Laktation, dass die Verluste aufsummiert über alle Laktationen trotz hoher Energiekonzentration im Futter nicht vollständig ausgeglichen werden.

Einen weiteren Hinweis auf die langanhaltenden Mobilisationsvorgänge der besonders milchbetonten Genotypen bietet der Laktationsverlauf der Milchinhaltsstoffgehalte (Tabelle 6 suppl.). Der Milchfettgehalt fällt bei HF und FV×RH5075 nach der Abkalbung am stärksten ab. Bei HF sinkt er als einzige Gruppe bis zum 99. Laktationstag. In allen anderen Gruppen liegt der Tiefpunkt ca. am 71. Laktationstag. Einerseits beeinflusst der hohe Anteil an Kraftfutter, also an Nichtfaserkohlenhydraten (NFC), die Menge und Zusammensetzung des MilCHFettes. Andererseits spielt der Energiemangel im 1. Laktationsdrittel ebenfalls eine bedeutende Rolle (KIRCHGESSNER et al. 2011). Der Eiweißgehalt zeigte dasselbe Muster in abgeschwächter Form. Die mobilisierbaren Proteinreserven sind begrenzt (KIRCHGESSNER et al. 2011). Der starke Rückgriff auf die Körperreserven mit steigender Milchleistung oder bei starker Betonung von Milchleistungsmerkmalen findet sich in zahlreichen anderen Untersuchungen (z. B. COFFEY et al. 2004, YAN et al. 2006, FRIGGENS et al. 2007).

Die Tabellen 6A und 2B (LEDINEK et al. 2019a,b) zeigen den Effekt des Laktationsstadiums ($p < 0,001$). Die höchste Futteraufnahme (21,49 kg TM/Tag; 162 g/kg LM^{0.75}) ging gemeinsam mit dem höchsten Kraftfutteranteil (33,1 %, 6,64 MJ NEL/kg TM) und der höchsten Nährstoffkonzentration der Ration am 71. Laktationstag einher. Mit fortschreitender Laktation sank die Effizienz wegen der abnehmenden Milchproduktion und der zunehmenden Lebendmasse. Der geringste Milchprotein- und Milchfettgehalt fielen auf den 43. und 71. Laktationstag in den Zeitraum der negativen Energiebilanz. Die höchste Effizienz fiel mit der höchsten Milchmenge und der geringen Futteraufnahme in der Frühlaktation zusammen. Die metabolische Umstellung von Trockenstehzeit und Trächtigkeit zur Laktation führt zu einer Depression der Futteraufnahme im perinatalen Zeitraum (INGVARTSEN und ANDERSEN 2000). Diese in der Frühlaktation deutlich gedämpfte Futteraufnahme trotz maximaler Milchleistung führte in der aktuellen Studie zu einer ca. 110 Tage andauernden negativen Energiebilanz. Die Kühe gaben teilweise unabhängig vom Nährstoffangebot Milch auf Basis mobilisierbarer Körperreserven. Dieses Phänomen prägten FRIGGENS et al. (2007) als „genetically driven body energy change“. Es sichert die Ernährung des Kalbes unabhängig vom tatsächlichen Nahrungsangebot und spiegelt die hohe metabolische Priorität der Milchproduktion wider (BAUMAN und CURRIE 1980, MARTENS 2013). Die Laktation wird in drei Teile geteilt: im 1. Drittel ist die Energiebilanz negativ, im 2. ausgeglichen und im 3. werden die Körperreserven wieder aufgebaut (BAUMAN und CURRIE 1980). Die Effizienz, mit der aufgenommene Nährstoffe in das Körpergewebe eingebaut werden, steigt mit fortschreitender

Laktation (YAN et al. 2006). Dies führt auch zur beobachteten BCS-Zunahme in der aktuellen Studie. Nach MARTENS (2013) wird bereits kurz vor der Abkalbung eine katabole Stoffwechselsituation beobachtet. Daraus ergibt sich die metabolische Notwendigkeit, Reserven für die Milchsekretion zu mobilisieren. Die homeorhetische Regulation des Energiestoffwechsels ermöglicht dies durch hohe Konzentrationen von Wachstumshormon, Cortisol, Prolaktin und Glucagon und niedrige Konzentrationen von Insulin, IGF-I und Leptin. Die darausfolgende Entkopplung der somatotropen Achse führt zu einer vorerst physiologischen Insulinresistenz und damit zu einer erhöhten Lipolyse und Gluconeogenese. Bei Kühen mit hoher Milchleistung ist diese Entkopplungsphase aufgrund unzureichender Feedback-Mechanismen verstärkt ausgeprägt (z. B. LUCY et al. 2009, MARTENS 2013).

Die Dauer der negativen Energiebilanz und die Intensität der Mobilisation nahmen in den letzten Jahrzehnten deutlich zu. Besonders die Betonung einer hohen Einsatzleistung gilt als Ursache (z. B. MARTENS 2013). Die lange andauernden Mobilisationsvorgänge von ca. 110 Tagen in der vorliegenden Studie stimmen damit überein. Sie weisen abermals auf das überdurchschnittliche Produktionsniveau verglichen zum österreichischen Durchschnitt hin (ZAR 2016). Die hohe Energiekonzentration verhinderte den BCS-Verlust nicht. YAN et al. (2006) zeigten, dass das Füttern einer energiereicheren Ration an spezialisierte Milchrassen nicht nur in einer zusätzlichen Nährstoffaufnahme mündete. Auch jener Anteil der zusätzlich aufgenommenen Nährstoffe, der in die Milchproduktion floss, stieg an. LUCY et al. (2009) belegten eine länger und stärker entkoppelte somatotrope Achse bei HF aus den USA verglichen mit zwei neuseeländischen HF-Linien. Ein verbessertes Futterangebot dämmte den größeren BCS-Verlust der US-Linie nicht ein. Bei der weniger milchbetonten neuseeländischen Linie trat keine Entkopplung auf. Die Konzentration des Wachstumshormons und die BCS-Veränderung waren bei der am schwächsten milchbetonten HF-Linie am geringsten, die IGF-I-Werte hingegen am höchsten. Auch Fleischerinder weisen keine Entkoppelung der somatotropen Achse auf (JIANG et al. 2005). Zusätzlich wirken sich eine hohe Milchleistung, eine negative Energiebilanz oder ihre sichtbaren Ausprägungen wie BCS- und Lebendmasseverlust negativ auf Fruchtbarkeit und Gesundheit aus (z. B. LUCY 2001, PRYCE et al. 2001, MARTENS 2013). Die durch die Insulinresistenz vermehrt angetriebene Lipolyse setzt NEFAs in den Blutkreislauf frei. Deren Gegenregulation durch Insulin schlägt durch die Entkopplung der somatotropen Achse fehl und begünstigt damit Hyperketonämien. Die damit verbundene Insulinresistenz gilt damit als „pathophysiologisch“ (MARTENS 2013). Neuere Studien untersuchen das Auftreten eines entzündlichen Zustandes der Leber und Stress im Endoplasmatischen Retikulum während des peripartalen Zeitraumes. Es wird als ein weiterer Punkt im Zusammenhang von Milchleistung, BCS, homeorhetische Regulation, Fettstoffwechsel und entzündlichen Erkrankungen z. B. von Gebärmutter und Euter gesehen (z. B. BERTONI et al. 2008, BRADFORD et al. 2015, GESSNER et al. 2015). Die negative Energiebilanz spielt darin eine Schlüsselrolle (MARTENS 2013). In der aktuellen Studie basierte die hohe Effizienz besonders im 1. Laktationsdrittel auf dem Abbau der Körperfettreserven.

Neben Milchbetonung bzw. Milchleistung, Genotyp, Laktationszahl und Laktationsstadium erwies sich die Lebendmasse innerhalb der Genotypen als Schlüsselfaktor für eine effiziente Milchproduktion (Tabellen 1C und 2C, Ledinek et al. 2019c).

In der aktuellen Studie zeigte sich eine nicht-lineare Beziehung von ECM und Effizienz zur Lebendmasse. Während die Futteraufnahme über den gesamten Lebendmassebereich anstieg, sank die Milchproduktion in den höchsten Lebendmasseklassen. Daher erreichten die Effizienz-

parameter ihr Maximum im leichteren bis mittleren Lebendmassebereich. Ab den Lebendmasseklassen 750 bis 800 kg verlor die Milchproduktion zunehmend an Effizienz. Zusätzlich fiel das Optimum der Lebendmasse-Effizienz in einen leichteren Bereich verglichen zur Nährstoff-Effizienz. Ein ähnliches Muster ergeben Auswertungen eines Datenmaterials aus Forschungsinstituten Deutschlands und Österreichs (GRUBER et al. 2017). Allerdings waren die Tiere leichter, die Lebendmasseklassen nur bis 775 kg vertreten und das Datenmaterial ca. 20 Jahre älter. Die somatotrope Achse regelt die Aufteilung der Nährstoffe zwischen Milchproduktion und Körpergewebe (LUCY et al. 2000, 2009). Zusätzlich dazu spiegelt ein hoher BCS ein geringeres Milchleistungspotenzial wider (BUCKLEY et al. 2000, DILLON et al. 2003, LEDINEK et al. 2019a,b). Eine wichtige Voraussetzung eines größeren und schwereren Körpers stellt demnach das genetische Potential für die Nährstoffaufteilung zu Wachstum und Körpergewebe dar. Dies erklärt, warum Kühe in den höheren Lebendmasseklassen mit gleichzeitig höherem BCS eine relativ geringere Milchleistung aufwiesen. VEERKAMP (1998) beschreibt eine moderat positive genetische Beziehung zwischen Lebendmasse und Milchmenge entsprechend jener von Milchmenge zu Körpermaßen. Die Voraussetzung dafür war die Berücksichtigung des BCS. Dieser korrelierte auch in der aktuellen Studie mit der Milchmenge negativ, mit der Lebendmasse positiv.

Mit steigender Milchbetonung verstärkte sich auch die Abhängigkeit einer effizienten Milchproduktion von der Lebendmasse (Gruber et al. 2017). Der Optimalbereich der milchbetonten Gruppen BS und HF fiel in einen kleineren und leichteren Lebendmassebereich. Effizienz und Milchleistung von FV blieben auf geringerem Niveau in einem weiteren Bereich stabil. Die Selektion auf Milchleistung änderte auch die Art der Nährstoffaufteilung zwischen Milchproduktion und Körpergewebe (LUCY et al. 2009) aufgrund der hohen Priorität der Milchleistung im Stoffwechsel des laktierenden Muttertieres (BAUMAN und CURRIE 1980). Daraus ergibt sich eine unterschiedliche Beziehung zwischen Futteraufnahme sowie Milchleistung zur Lebendmasse in Doppelnutzungs- und spezialisierten Milchrassen. Zudem sind jene Ressourcen, die zwischen Milchleistung, Erhaltung (Körpergewebe, BCS), Fruchtbarkeit und Gesundheit verteilt werden, knapp (HUBER 2018). Eine gewichtige Ursache stellt die unzureichende Nährstoffaufnahme im 1. Laktationsdrittel dar (BAUMAN und CURRIE 1980). Daraus schließend beeinflusst eine geringe Veränderung der Prioritäten in Richtung Lebendmasse und BCS entlang der Lebendmasseklassen die Nährstoffaufteilung in Richtung Milchproduktion spezialisierter Milchrassen stärker.

Die Lebendmasse der FV-Gruppen bis zu durchschnittlich 25 % RH-Anteil lag zwischen 722 und 729 kg, von HF und BS bei 662 und 649 kg (LEDINEK et al. 2019a,b). Damit befanden sich die leichteren milchbetonten Typen in deren Optimum einer futter-effizienten Milchproduktion. Die FV-Gruppen bis zu durchschnittlich 12,5 % RH-Anteil bewegten sich an der oberen Grenze ihres Optimalbereiches. FV×RH25 überschritt seinen Optimalbereich zwischen 500 und 700 kg aufgrund des bereits kleiner ausfallenden Bereiches bei einer gleichzeitig hohen Lebendmasse. Bezüglich Lebendmasse-Effizienz befanden sich alle Genotypen im oberen Grenzbereich oder je nach Formung der Kurve auch außerhalb.

Das Datenmaterial der aktuellen Studie basiert auf einem Zeitraum von einem Jahr in österreichischen Milchviehbetrieben. Die meisten Genotypen liegen im derzeitigen Optimalbereich einer futter-effizienten Milchproduktion innerhalb ihrer Population. Allerdings sind die Grenzen einer optimalen lebendmasse-effizienten Milchproduktion erreicht bzw. überschritten. Wie sieht jedoch die Entwicklung der Lebendmasse in den letzten Jahrzehnten aus?

Obwohl sich Untersuchungen zum Zusammenhang von Milchleistung, Lebendmasse und Effizienz bereits über Jahrzehnte erstrecken (z. B. MASON et al. 1957, HOOVEN et al. 1968), ist die (genetische) Beziehung zwischen Milchleistung und Lebendmasse schwer zu erfassen. Unzureichende Messungen, Lebendmasseverlust durch Mobilisation oder uneinheitliche Erhebungszeitpunkte überlagern den Zusammenhang und führen zu widersprüchlichen Ergebnissen (VEERKAMP 1998). Demnach lassen die schwach positive phänotypische ($r = 0,12$) und die schwach negative genetische Korrelation (Fleckvieh: $r = -0,23$, KÖCK et al. 2018a) der aktuellen Studie nicht auf einen fehlenden Zusammenhang schließen. Nach der Berücksichtigung des BCS und der Review zahlreicher Studien stellte VEERKAMP (1998) einen mittleren positiven genetischen Zusammenhang fest.

Bereits frühere Studien zeigen eine optimale Lebendmasse im Populationsmittel (HOOVEN et al. 1968, MILLER und HOOVEN 1969, BROWN et al. 1977). Seither stieg nicht nur die Milchleistung (ZAR 2016), sondern auch die Lebendmasse der Tiere. HANSEN (2000) stellte fest, dass Milchleistung, Sharpness und Körpergröße von HF in den USA in den letzten Jahrzehnten zunahm. In Bayern beschreibt KROGMEIER (2009) eine Zunahme der Körpergröße bei BS und FV. Vergleiche von neueren österreichischen Studien (GRUBER und STEGFELLNER 2015, LEDINEK et al. 2019a,b) mit früheren Versuchen weisen auf einen ansteigenden Trend der Lebendmasse in BS und HF (HAIGER et al. 1987) sowie HF und FV (GRUBER et al. 2017) hin. Ein Blick in vor einigen Jahrzehnten gängigen Fach- und Lehrbüchern zeigt um ca. 100 bis 150 kg leichtere Tiere (NEHRING 1963, KIRCHGESSNER 1970, BECKER 1971, SPIEKERS und POTTHAST, 2003). Allerdings sind auch überlappende Effekte zur Lebendmasseentwicklung zu bedenken, z. B. übliche Kreuzungen mit leichteren RH. Weiters verringert ein Anstieg des Milchleistungspotenziales der Doppelnutzungsrasse Fleckvieh Bemuskelung und BCS bei einem gleichzeitig größer werdenden Rahmen. Deskriptiv ausgewertete Daten der linearen Beschreibung österreichischer Kühe von 2000 bis 2017 zeigen eine Zunahme der Kreuzhöhe bei gleichzeitiger Abnahme der Bemuskelung (FÜRST et al. 2017). Allerdings liegt keine Erhebung der Lebendmasse infolge der linearen Erstbeschreibung vor. Die Versteigerungsdaten der Erstlingskühe in den Jahren 2000 bis 2017 und die Schlachtgewichte der FV-, HF- und BS-Kühe in den Jahren 2008 bis 2017 ergeben keine Zunahme der Lebendmasse (FÜRST 2019, persönl. Mitteilung 24. Juli 2019). Allerdings ergibt sich bei den Erstlingskühen ein Trend zu jüngeren Tieren mit ca. 100 Tagen seit 2000 (FÜRST et al. 2017). Insgesamt nehmen Kreuzhöhe und Rahmen zu und die Bemuskelung geht zurück.

Den Preis schwerer Tiere stellt ein höherer Erhaltungsbedarf dar (GfE 2001). Schwere Kühe müssen für die gleiche Effizienz mehr Milchleistung erbringen als leichtere. Dafür benötigen sie eine höhere Energiekonzentration in der Ration (STEINWIDDER 2009). Lebendmasse und Effizienzmerkmale korrelierten negativ (z. B. DICKINSON et al. 1969, VALLIMONT et al. 2011, GRUBER und STEGFELLNER 2015, KÖCK et al. 2018a, LEDINEK et al. 2019b). Die genetische Korrelation zwischen ECM und Futteraufnahme liegt zwischen 0,49 (Brown Swiss) und 0,65 (Fleckvieh) in der aktuellen Studie (KÖCK et al. 2018a). Dies erklärt auch, weshalb die züchterische Betonung der Milchleistung ohne Beachtung der Futteraufnahme zu einer dafür nicht ausreichend ansteigenden Futteraufnahme führt, höhere Energiekonzentrationen und eine verstärkte Mobilisation fordert. Die Ursache ist die Entkoppelung der Milchproduktion von der tatsächlichen Nährstoffaufnahme in den ersten Laktationswochen, also jene physiologische Anpassung des Muttertieres zur sicheren Ernährung des Nachkommens (MARTENS 2013). Damit stellt die zu geringe Futteraufnahmekapazität den limitierenden Faktor dar. Rückschließend bedeutet eine höhere Fut-

teraufnahmekapazität bei gleichbleibendem Milchleistungsniveau wiederum größere und damit auch schwerere Tiere (mit höherem Erhaltungsbedarf). Zusätzlich dazu verdeutlichte der Vergleich mit dänischen HF (KRISTENSEN et al. 2015), dass die HF-Kühe der aktuellen Studie alleine der höheren Lebendmasse wegen die Lebendmasse-Effizienz der dänischen Tiere nicht erreichen. Eine hohe Lebendmasse wirkt sich negativ auf Fruchtbarkeit, Gesundheit, Klauengesundheit, Fundament oder Nutzungsdauer aus (z. B. HANSEN et al. 1999, KROGMEIER 2009). Gesundheitliche Probleme bestätigt auch die aktuelle Studie (KÖCK et al. 2018a) durch eine mittlere positive genetische Korrelation zwischen Lahmheit und Lebendmasse.

Eine Zucht auf Effizienz führte zu leichten aber stark mobilisierenden Tieren mit niedrigem BCS (VALLIMONT et al. 2011). Auch in der aktuellen Studie (KÖCK et al. 2018a) zeichneten sich die genetisch effizienteren Kühe aller Rassen durch eine höhere Milchmenge, eine etwas höhere Futteraufnahme, einen niedrigeren BCS und eine geringere Lebendmasse aus. Zusätzlich neigten besonders effiziente und daher leichtere Fleckvieh-Kühe zu geringerer Lahmheit. Effizientere Kühe zeigten auch einen höheren Fett-Eiweiß-Quotienten, deutlich längere Zwischenkalbezeiten und ein vermehrtes Auftreten von Stillbrunst und Zysten (KÖCK et al. 2018b). Die Abgangsraten fielen bei effizienteren Tieren jedoch am geringsten aus. Trotz geringerer Fruchtbarkeit gingen effizientere Tiere nicht häufiger wegen Unfruchtbarkeit ab. Dies weist auf eine Sonderbehandlung dieser Tiere hin. Kühe mit niedriger Effizienz gingen besonders häufig aufgrund geringer Leistung, hohen Alters oder Verkaufs ab. Insgesamt erwiesen sich Kühe mit mittlerer Effizienz als optimal. Sie kombinieren eine hohe Milchleistung mit guter Fruchtbarkeit und Gesundheit (KÖCK et al. 2018b).

Eine Selektion auf geringere Lebendmasse bzw. Effizienz bedarf der Berücksichtigung des BCS. Dies ermöglicht die Unterscheidung zwischen großen Tieren mit geringem BCS und kleinen Tieren mit normalem BCS (KÖCK et al. 2018a). Die Heritabilitäten von Fleckvieh bewegten sich zwischen 0,11 für Energie-Effizienz und 0,44 für die Lebendmasse mit hohen Wiederholbarkeiten zwischen 0,30 und 0,83. Die Heritabilitäten fielen für Brown Swiss und Holstein-Friesian generell geringer aus. Die Wiederholbarkeit entsprach jener von Fleckvieh. Futteraufnahme und ECM waren geringer erblich verglichen mit Datensätzen aus Forschungsherden, die genetischen Korrelationen hingegen ähnlich (z. B. MANZANILLA-PECH et al. 2014). Insgesamt bewegten sich die genetischen Parameter im literaturüblichen Rahmen (z. B. MANZANILLA-PECH et al. 2014, LI et al. 2016, HURLEY et al. 2017). Dies spricht für die ausreichende genetische Variabilität der Effizienzmerkmale trotz der Verwendung von Felddaten und der Schätzung der Futteraufnahme. Weiters wurden multivariate Testläufe für die Bewertung indirekter Merkmale zur Schätzung der Energie-Effizienz und Energieaufnahme vorgenommen (EGGER-DANNER et al. 2018). Zuchtwertkorrelationen einer mit ECM und Lebendmasse indirekt geschätzten Energieaufnahme liegen zwischen 0,91 (Holstein) und 0,95 (Fleckvieh). Allerdings ist hier zu berücksichtigen, dass die Projektbetriebe ein sehr einheitliches und überdurchschnittliches Niveau aufwiesen und die Futteraufnahme geschätzt ist (LEDINEK et al. 2019a). KÖCK et al. (2018a) verweisen auf die daraus sinkende genetische Variation. Die unterschiedliche Entwicklung der Effizienzmerkmale über alle Laktationszahlen hinweg (LEDINEK et al. 2019b) sowie die sich unterscheidenden Optima zeugen von der Wichtigkeit von Fütterungsinformationen zur Beurteilung der Nährstoff-Effizienz.

3.4 Schätzung der Lebendmasse

Die Tabellen 4E und 5E sowie die Abbildung 1E stellen die Vorhersagemodelle, Einflussfaktoren und p-Werte dar. Angaben zur Validierung finden sich in Tabelle 6E und in Abbildungen 2E und 3E (GRUBER et al. 2018).

Die genaue Schätzung der Lebendmasse setzt einfach und gut messbare Körpermaße voraus, welche einen möglichst engen Zusammenhang zur Lebendmasse aufweisen. Es zeigte sich, dass Schätzmodelle mit Umfangsmaßen wie Brust- und Bauchumfang deutlich besser abschnitten (HEINRICHS et al. 1992, 2017, YAN et al. 2009, LEDINEK und GRUBER 2015, STEGFELLNER 2014). Modelle mit rein linearen Maßen verursachten deutlich höhere Schätzfehler (HAILE-MARIAM et al. 2014). In den Modellen der aktuellen Studie mit nur einem Körpermaß erreichten Brustumfang (HG, heart girth, RMSE = 39,0 kg), Bauchumfang (BG, belly girth, RMSE = 39,3 kg) und Hüftbreite (HW, hip width, RMSE = 49,9 kg) den geringsten Schätzfehler. Alle anderen Maße und auch der BCS bewegten sich zwischen 51,9 und 57,0 kg (Rumpftiefe, hintere Körperbreite). Die Kombination mehrerer Körpermaße verringerte den Schätzfehler deutlich. Die gemeinsame Verwendung von mit Brust- und Bauchumfang im Modell_{HG BG} reduzierte den Schätzfehler auf 32,5 kg. Das Testen eines dritten Körpermaßes ergab Modell_{HG BG HW} als jenes mit dem geringsten Schätzfehler (RMSE = 30,4 kg). In den genauesten Modellen fanden sich jene Körpermaße mit der stärksten Korrelation zur Lebendmasse wieder. Modelle mit drei Körpermaßen ohne Umfangsmaß erreichten nicht einmal die Schätzgenauigkeit der Modelle mit Brust- und Bauchumfang als einziges Körpermaß. YAN et al. (2009) erklären dies mit dem starken Zusammenhang von Umfangsmaßen zur Körperkondition. Bereits ENEVOLDSEN und KRISTENSEN (1997) testeten den BCS für die Lebendmasseschätzung. Ergab sich bei ausgebildeten und erfahrenen Versuchstechnikern eine hohe Schätzgenauigkeit (LEDINEK und GRUBER 2014, STEGFELLNER 2014), so erreichte der BCS bei weniger erfahrenen Bewertungspersonen einen Schätzfehler von 53,7 kg in der aktuellen Studie. In der Studie von FERGUSON et al. (1994) wichen die Scores erfahrener Bewertungspersonen in 32,6 % der Messungen um 0,25 Punkte von einem Goldstandard ab, bei immerhin 9,3 % um 0,5 Punkte. Unerfahrene Erhebungspersonen schnitten deutlich schlechter ab (KLEIBÖHMER et al. 1998). Zusätzlich zur Subjektivität der Bewertungen lösen bereits geringe Abweichungen des BCS hohe Abweichungen in der geschätzten Lebendmasse aus. Dies liegt an den hohen Regressionskoeffizienten von ca. 60 kg pro Punkt. Der BCS eignet sich damit nicht für die Lebendmasseschätzung. Für die Bewertung der Mobilisation von Körpergewebe ist weniger der absolute Wert, sondern die BCS-Veränderung ausschlaggebend.

Die fixen Effekte Genotyp, Laktationszahl und physiologisches Stadium sowie die Regressionskoeffizienten aller Körpermaße beeinflussten die Lebendmasse signifikant ($p < 0,001$). Die degressive Zunahme der Lebendmasse mit der Laktationszahl spiegelte das Wachstum der Tiere wider (ENEVOLDSEN und KRISTENSEN 1997, YAN et al. 2009). Während der Trockenstehzeit stieg der Einfluss des Laktationsstadiums auf die Lebendmasse. In diesem letzten Trächtigkeitsdrittel gewinnt der gravide Uterus besonders an Gewicht (BELL et al. 1995). In der Laktation lässt sich der Einfluss des physiologischen Stadiums als Polynom 4. Grades beschreiben. Der Tiefpunkt mit geringster Lebendmasse findet sich bei Modell_{HG BG HW} am 114. Tag. ANDREW et al. (1994) fanden den geringsten Körperenergiegehalt am 77. Tag bei nicht signifikant geringerer Lebendmasse verglichen zu anderen Laktationsstadien. Ähnlich der aktuellen Studie zeigte dieses Ergebnis, dass die Lebendmasse ähnlich dem Bauchumfang nicht nur von Mobilisationsvorgängen, son-

dern auch von der Füllung des Verdauungstraktes geprägt war. Der Laktationsverlauf des Brustumfanges ähnelt hingegen jenem des BCS (Daten nicht gezeigt).

Die genotyp-spezifischen Regressionskoeffizienten schlüsselten die unterschiedliche Bedeutung der Körpermaße für die Lebendmasse der Genotypen auf (Abbildung 1E, GRUBER et al. 2018). Mit ansteigendem RH-Anteil verringerte sich nicht nur die Körperkondition, sondern auch der Einfluss des Brustumfanges auf die Lebendmasse. Jener des Bauchumfanges stieg an. Die Diskussion dieser kontinuierlichen Veränderung von Merkmalen mit ansteigendem Anteil der spezialisierten Milchrasse RH in der Zweinutzungsrasse Fleckvieh findet sich in den vorangehenden Kapiteln.

Die Validierung von Modell_{HG BG} und Modell_{HG BG HW} teilte den MSPE (Mean Square Prediction Error) in den ECT (error due to central tendency), ER (error due to regression) und ED (error due to disturbance) auf (Bibby und Toutenburg 1977). Der Zufall verursachte durchschnittlich 99,6 % der Varianz. Die linearen Regressionen zwischen Residuen und zentrierten vorhergesagten Werten beider Modelle sprechen für eine valide Schätzung der Lebendmasse ohne systematische Abweichungen (ST-PIERRE 2003). Insgesamt erklärten die Schätzmodelle ca. 80,0 % der Varianz der beobachteten Werte in der Trockenstehzeit und Modell_{HG BG HW} 83,5 % in der Laktation. Lebendmasseschätzformeln mit deutlich höheren Schätzgenauigkeiten (z. B. RMSPE = 23,9 kg, R^2 = 91 %, YAN et al. (2009)) stammen ähnlich wie bei LEDINEK und GRUBER (2015) von einer relativ geringen Datenanzahl aus Forschungsherden. Damit sind sie hauptsächlich in sich sehr valide. HAILE-MARIAM et al. (2014) erreichen bei einer 10-fachen Kreuzvalidierung ein R^2 von 47 % mit Daten der linearen Beschreibung. Die deutlich ungenauere Beschreibung der Lebendmasse begründet sich in den verwendeten Merkmalen. Es fließen keine Umfangsmaße, sondern nur lineare Maße plus BCS ein. Ähnlich der aktuellen Studie bewegte sich der Schätzfehler in Modellen ohne Umfangsmaße in einem Bereich von 50 kg.

3.5 Schlussfolgerungen

Die Studie ermöglichte einen breiten Einblick in ein kontinuierliches Spektrum zwischen Doppelnutzungsrasse und spezialisierter Milchrasse basierend auf deren unterschiedlichem Stoffwechsel sowie in die Fütterung österreichischer Milchviehbetriebe.

Die Zusammensetzung der Rationen spiegelte deutlich die Aufteilung Österreichs in klimatisch begünstigte Regionen (Maissilage) und bergige Regionen (Dauergrünland) wider. Kraftfutter wurde hauptsächlich über Abrufstationen tierindividuell verabreicht. Der geringe Anteil an reinen Grundfütterationen und Weide weist auf das überdurchschnittliche Produktionsniveau der Projektbetriebe hin.

Die genetischen Parameter der Effizienzmerkmale ließen auf eine ausreichende genetische Variabilität der in dieser Studie verwendeten Felddaten schließen. Die Schätzung der Futteraufnahme basierend auf tierindividuellen Daten bietet damit wertvolle Informationen zur weiteren Nutzung in der Rinderzucht. Diese Herangehensweise erweist sich als sinnvoll, wenn keine ausreichenden Datenbestände aus Testbetrieben vorliegen.

Hohe Effizienz begründet sich auf einem höheren Anteil an Nährstoffen, die der Milchproduktion dienen, und auf die Mobilisation von Körpergewebe. Die besonders hohe Effizienz und Milchleistung im 1. Laktationsdrittel wird durch eine vom tatsächlichen Nährstoffbedarf entkoppelten Milchleistung getragen und mündet in einer ausgedehnten katabolen Stoffwechselsituation.

Je höher die Spezialisierung eines Genotyps auf Milchleistung, desto effizienter ist die Milchproduktion, jedoch trotz energiereicher Rationen auf Kosten der Körperreserven. Daher nutzt eine Zucht auf Effizienz die metabolische Priorität der Milchproduktion vor allem in der frühen Laktation. Sie verschärft das Energiedefizit und damit verbundene Probleme mit Gesundheit und Fruchtbarkeit. Effizientere Kühe zeigen einen höheren Fett-Eiweiß-Quotienten, deutlich längere Zwischenkalbezeiten und ein vermehrtes Auftreten von Stillbrunst und Zysten. Kühe mit mittlerer Effizienz kombinieren hingegen eine hohe Milchleistung mit guter Fruchtbarkeit und Gesundheit.

Weiters zeigte sich ein optimaler Lebendmassebereich für die höchste Effizienz. Schwere Kühe (> 750 kg) produzierten sogar weniger Milch. Die Effizienz milchbetonter Genotypen ist in höherem Maße von der Lebendmasse beeinflusst als von Fleckvieh oder FV mit geringem RH-Anteil. Die Beziehung zwischen Futteraufnahme, Lebendmasse und Milchleistung unterscheidet sich zwischen spezialisierten Milchrassen und Doppelnutzungsrasen

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4 Zusammenfassung

Das Ziel der Studie war die Entwicklung von

tabilitäten von BCS und LAME waren jeweils 0,19 und 0,07. Die Wiederholbarkeit befand sich auf hohem Niveau von 0,30 bei Energie-Effizienz bis 0,83 für Leb

5 Abstract

The aim of the study was to develop efficiency traits for Austrian cattle breeding in order to reduce the environmental impact of dairying. Furthermore, breeding of more efficient cows helps in a situation of more volatile producer prices by decreasing feeding costs.

The phenotypic studies characterize diets used on-farm and examine the phenotypic relationship between efficiency and efficiency related (animal specific) traits like nutrient and feed intake (DMI), body weight, milk yield, body condition score (BCS) and energy balance. Furthermore, the question was answered, if an optimum body weight for highest efficiency exists. Another objective was to show the impact of an increasing Red Holstein (RH) proportion in Fleckvieh (FV), the spectrum between dual-purpose and specialized dairy breeds. Data came from 161 farms, 6105 cows, observed at each performance testing day in 2014 (project 'Efficient Cow'). The following efficiency traits were considered: body weight efficiency as the ratio between energy corrected milk (ECM) to metabolic body weight, feed efficiency (kg ECM per kg DMI) and energy efficiency expressed as the ratio between energy in milk to energy intake. Last but not least body weight was predicted from body size measurements and other animal data in the lactation and dry periods.

Most diets were grass silage- or maize silage-based. Nearly half (42.8%) of the records were diets with separately fed concentrate or were partial mixed rations (PMR, 42.9%), and 12.0% were total mixed rations (TMR). Feedstuffs from permanent grassland ranged between 62% (TMR) and 84% (pure forage diets) of forage. Partial mixed rations and TMR showed the highest average proportion of maize silage (30%). The low importance of pure forage diets and pasture reflected the above-average production level of the farms.

Most production traits increased from pure FV over FV groups with increasing RH genes to Holstein Friesian (HF). The FV group with highest RH proportion and HF had the highest ECM and DMI (29.3 vs. 29.2 kg ECM/d; 20.8 vs. 20.9 kg DMI/d). Brown Swiss (BS) and FV had lower levels (26.5 vs. 26.7 kg ECM/d; 19.8 vs. 19.7 kg DMI/d). Body condition declined in relation to proportion of RH genes from pure FV to HF (FV 3.42 Pt., BS 2.88 Pt., HF 2.61 Pt.). The higher the proportion of RH in FV, the more efficiently milk was produced, but also at the expenses of body fat reserves. The negative energy status of HF and the FV groups with highest RH proportion lasted approximately twice as long as of the least efficient BS. All genotypes regained lost body tissue during whole lactation. The high yielding groups required a higher concentrate proportion in late lactation to regain body condition. In early lactation high efficiency was accompanied by the loss of body weight and BCS.

An optimum body weight range for efficiency does exist, due to the non-linear relationship of milk yield and body weight. Milk yield decreased in cows above the 750 kg body weight class for HF, BS and FV×RH with 68% RH genes, but less dramatically and later for pure FV at 800 kg. BS and HF had the highest nutrient efficiency in a narrower and lower body weight range (550 to 700 kg) due to a stronger curvature of the parabolic curve. Contrary to this, the efficiency of FV did not change as much as it did in the dairy breeds with increasing body weight, meaning that pure FV had a similar feed and energy efficiency in a range of 500–750 kg. The breed differences disappeared when body weight ranged between 750 and 800 kg. In specialized dairy breeds, with increasing body weight the efficiency decreased to a higher degree than with dual-purpose breeds. The average body weight of the breeds studied (pure FV 722 kg, BS 649 kg, HF 662 kg) was in the optimum range of nutrient efficiency. Pure FV is located at the upper end of the decreasing segment. As optimum of body weight efficiency occurs in the lower body weight range, all genotypes were at the upper end or too heavy.

Based on the phenotypic results, the genetic objective was to estimate genetic parameters for the efficiency (related) traits and to investigate their relationships with BCS and lameness (LAME). The breed classification oriented to the common classification for breeding evaluation in Austria. For Fleckvieh, the heritability estimates of the efficiency (related) traits ranged from 0.11 for energy efficiency to 0.44 for body weight. Heritabilities for BCS and LAME were 0.19 and 0.07, respectively. Repeatabilities were high and ranged from 0.30 for energy efficiency to 0.83 for body weight. Heritability estimates were generally lower for Brown Swiss and Holstein. However, as less records were available for these breeds, standard errors were also slightly higher. Repeatabilities were in the same range as for Fleckvieh. In all three breeds, more efficient cows were found to have a higher milk yield, lower body weight, slightly higher DMI and lower BCS. Higher efficiency was associat-

ed with slightly less lameness problems, most likely due to the lower body weight (especially in Fleckvieh). Body weight and BCS were positively correlated with each other. Therefore, when selecting for a lower body weight, BCS is required as additional information since otherwise no distinction between large animals with low BCS and smaller animals with normal BCS is possible.

Body measurements were tested as single predictors and in multiple regressions according to their prediction accuracy and their correlations with body weight. Within the prediction models with a single body measurement, heart girth influenced relationship with body weight most, with a lowest root mean square error (RMSE) of 39.0 kg, followed by belly girth (39.3 kg) and hip width (49.9 kg, HW). All other body measurements and BCS resulted in a RMSE of higher than 50.0 kg. The model with heart and belly girth (Model_{HG BG}) reduced RMSE to 32.5 kg, and adding HW reduced it further to 30.4 kg (Model_{HG BG HW}). As RMSE and the coefficient of determination improved, genotype-specific regression coefficients for body measurements were introduced in addition to the pooled ones. The most accurate equations, Model_{HG BG} and Model_{HG BG HW}, were validated separately for the lactation and dry periods. Root mean square prediction error (RMSPE) ranged between 36.5 and 37.0 kg (Model_{HG BG HW}, Model_{HG BG}, lactation) and 39.9 and 41.3 kg (Model_{HG BG HW}, Model_{HG BG}, dry period). For validation the mean square prediction error (MSPE) was decomposed into error due to central tendency, error due to regression, and error due to disturbance. On average, 99.6% of the variance between estimated and observed values was caused by disturbance, meaning that predictions were valid and without systematic estimation error.

The study allowed a broad view on the continuous spectrum between dual-purpose and dairy breeds due to the different characteristics of metabolism and on the common diets on Austrian dairy farms. High efficiency required an increasing partitioning of nutrients to milk yield inclusive mobilization and a more intense feeding. Therefore breeding for higher efficiency, if it is driven by milk yield, would exacerbate catabolic status and the use of human-edible feed stuff. Cows with medium weights within population are the most nutrient efficient ones. However, they were too heavy as to be at their peak of optimum body weight efficiency. The lower body weight of the more efficient cows reduced lameness. A further increase of dairy cows' body weights should hence be avoided. Overall, the results highlight the necessity of a broader definition of efficiency in cattle breeding involving parameters like BCS, health and fertility traits. As body weight is an important trait for both management and breeding, the measurement and use of a combination of both heart girth and belly girth are recommended if the use of scales is impossible.

6 Persönliche Publikationsliste

6.1 Originalbeitrag in Fachzeitschrift mit Review

- EGGER-DANNER, C., A. KÖCK, C. FÜRST, M. LEDINEK, F. STEININGER, K. ZOTTL, B. FÜRST-WALT, 2018: Indirekte Merkmale der Futtereffizienz bei Milchkühen. *Züchtungskunde* 90, 467-475.
- GRUBER, L., M. LEDINEK, F. STEININGER, B. FÜRST-WALT, K. ZOTTL, M. ROYER, K. KRIMBERGER, M. MAYERHOFER und C. EGGER-DANNER, 2018: Body weight prediction using body size measurements in Fleckvieh, Holstein and Brown Swiss dairy cows in lactation and dry period. *Arch. Anim. Breeding* 61, 413-424.
- KÖCK, A., M. LEDINEK, L. GRUBER, F. STEININGER, B. FÜRST-WALT und C. EGGER-DANNER, 2018: Genetic analysis of efficiency traits in Austrian dairy cattle and their relationships with body condition score and lameness. *J. Dairy Sci.* 101, 445-455.
- LEDINEK, M., L. GRUBER, F. STEININGER, B. FÜRST-WALT, K. ZOTTL, M. ROYER, K. KRIMBERGER, M. MAYERHOFER und C. EGGER-DANNER, 2016: Efficient Cow – Estimation of feed intake for efficiency traits using on-farm recorded data. *Acta Agric. Slovenica (Suppl. 5)*, 71-75.
- LEDINEK, M., L. GRUBER, F. STEININGER, K. ZOTTL, M. ROYER, K. KRIMBERGER, M. MAYERHOFER, C. EGGER-DANNER und B. FÜRST-WALT, 2019: Analysis of lactating cows in commercial Austrian dairy farms: Diet composition, and influence of genotype, parity and stage of lactation on nutrient intake, body weight and body condition score. *It. J. Anim. Sci.* 18, 202-214.
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- LEDINEK, M., L. GRUBER, F. STEININGER, B. FÜRST-WALT, K. ZOTTL, M. ROYER, K. KRIMBERGER, M. MAYERHOFER und C. EGGER-DANNER, 2019: Analysis of lactating cows on commercial Austrian dairy farms: Influence of genotype and body weight on efficiency parameters. *Arch. Anim. Breeding*.

6.2 Publizierter Beitrag für wissenschaftliche Veranstaltung

- EGGER-DANNER, C., B. FÜRST-WALT, C. FÜRST, L. GRUBER, M. LEDINEK, F. STEININGER, W. ZOLLITSCH und K. ZOTTL, 2017: Internationale Entwicklungen und Herausforderungen zur Zucht auf die effiziente Kuh. Seminar des Ausschusses für Genetik der ZAR 9. März 2017, Salzburg, Konferenzbericht, 3-9.
- EGGER-DANNER, C., F. STEININGER, L. GRUBER, M. LEDINEK, K. ZOTTL, W. ZOLLITSCH, C. FÜRST, W. OBRITZHAUSER, J. BURGSTALLER, J. KOFLER und B. FÜRST-WALT, 2016: Das „Efficient Cow“ Projekt. 6. Kremesberger Tagung 16. Feb. 2016, 29-39.
- FÜRST-WALT, B., F. STEININGER, C. FÜRST, L. GRUBER, M. MAYERHOFER, M. LEDINEK, W. ZOLLITSCH, und C. EGGER-DANNER, 2016: First results of the Austrian Efficient Cow project. *Braunvieh Weltkongress* 6.-8. April 2016, Mende, Konferenzband, 32-37.
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- GRUBER, L. und M. LEDINEK, 2017: Einfluss der Lebendmasse auf die Effizienz von Milchkühen. Seminar des Ausschusses für Genetik der ZAR 9. März 2017, Salzburg, Konferenzbericht, 18-28 Druckausgabe, 18-30 online-Ausgabe.
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- KÖCK, A., M. LEDINEK, L. GRUBER, F. STEININGER, B. FÜRST-WALT und C. EGGER-DANNER, 2018: Zusammenhang Effizienz und Gesundheit. 8. Kremesberger Tagung 23. März 2018, Pottenstein, Bericht Veterinärmedizinische Universität Wien, 9-16.
- LEDINEK, M., L. GRUBER, F. STEININGER, B. FÜRST-WALT, K. ZOTTL, M. ROYER, K. KRIMBERGER, M. MAYERHOFER und C. EGGER-DANNER, 2016: Efficient Cow – Estimation of feed intake for efficiency traits using on-farm recorded data. 24th International Symposium Animal Science Days 21.-23. Sept. 2016, Ptuj.

- LEDINEK, M., L. GRUBER, F. STEININGER, B. FÜRST-WALT, K. ZOTTL, M. ROYER, K. KRIMBERGER, M. MAYER-HOFER und C. EGGER-DANNER, 2017: Futter- und Nährstoffeffizienz – was steckt dahinter? Seminar des Ausschusses für Genetik der ZAR 9. März 2017, Salzburg, Konferenzbericht, 10-17.
- LEDINEK, M., L. GRUBER, F. STEININGER, B. FÜRST-WALT, M. ROYER, K. ZOTTL und C. EGGER-DANNER, 2017: Influence of live weight and genotype on efficiency of dairy cows. EAAP Annual Meeting 28. Aug. - 2. Sept. 2017, Tallinn, In: Wageningen Academic Publishers (Hrsg.), Book of Abstracts of the 68th Annual Meeting of the European Federation of Animal Science.
- LEDINEK, M., L. GRUBER, F. STEININGER, B. FÜRST-WALT, K. ZOTTL, M. ROYER, K. KRIMBERGER, M. MAYER-HOFER und C. EGGER-DANNER, 2019: Analyse österreichischer Milchviehbetriebe im Projekt „Efficient Cow“: Rationsgestaltung und Einfluss des Genotyps auf Produktions- und Effizienzmerkmale. 46. Viehwirtschaftliche Fachtagung 10.-11. April 2019, Bericht HBLFA Raumberg-Gumpenstein, 57-69.
- STEININGER, F., C. EGGER-DANNER, K. ZOTTL, M. MAYERHOFER, W. ZOLLITSCH, M. LEDINEK, L. GRUBER, B. FÜRST-WALT und C. FÜRST, 2015: Efficient Cow - strategies for on-farm collecting of phenotypes for efficiency traits. ICAR (International Committee of Animal Recording), ICAR Technical Series no. 19.
- STEININGER, F., M. LEDINEK, L. GRUBER, B. FÜRST-WALT, K. ZOTTL, und C. EGGER-DANNER, 2016: Recording of feed efficiency under on-farm conditions. EAAP Annual Meeting 29. Aug. - 2. Sept. 2016, Belfast, In: Wageningen Academic Publishers (Hrsg.), Book of Abstracts of the 67th Annual Meeting of the European Federation of Animal Science, 648.
- ZOTTL, K., A. KOECK, B. FÜRST-WALT, C. PFEIFFER, F. STEININGER, L. GRUBER, M. LEDINEK und C. FÜRST, 2016: On farm recording of novel traits – genetic parameters and recommendations. 40. ICAR BIENNIAL SESSION 24.-28. Okt. 2016, Puerto Varas, ICAR Technical Series no. 21, 287-290.

6.3 Wissenstransfer

- EGGER-DANNER, C., B. FÜRST-WALT, F. STEININGER, M. LEDINEK, R. WEISSENSTEINER, L. GRUBER, W. ZOLLITSCH, K. ZOTTL und C. FÜRST, 2015: 2. Zwischenbericht Efficient Cow: Analyse und Optimierung der Produktionseffizienz und der Umweltwirkung in der österreichischen Rinderwirtschaft. Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft, Amt der Niederösterreich, Oberösterreich, Salzburger, Burgenländischen, Tiroler, Vorarlberger, Steiermärkischen und Kärntner Landesregierung, 43.
- GRUBER, L., und M. LEDINEK, 2017: Wie wirkt sich die steigende Lebendmasse auf die Nährstoff-Effizienz unserer Milchkühe aus? Das österreichische Magazin für Fleckviehzucht 2017, Heft 4, 6-9.
- LEDINEK, M., L. GRUBER, F. STEININGER, B. FÜRST-WALT, K. ZOTTL, M. ROYER, K. KRIMBERGER, M. MAYER-HOFER und C. EGGER-DANNER, 2017: Efficient Cow - wesentliche Produktionsdaten und Effizienzparameter unserer Milchkühe. St. Andäer Agrarwoche, Rindertag 02. Feb. 2017.
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6.4 Populärwissenschaftlicher Beitrag

- GRUBER, L., M. LEDINEK und F. STEININGER, 2014: "Efficient Cow" Auf der Suche nach der idealen Kuh. Der fortschrittliche Landwirt 8, 18-20.
- GRUBER, L., und M. LEDINEK, 2018: Schwere Kühe haben's schwer. Der fortschrittliche Landwirt 2, 20-22.

Anhang

Tabelle 1 suppl.: Datenverteilung der Grundfuttertypen innerhalb des Fütterungssystems.

Forage type*	Feeding system [¶]			
	FOR	SEP	PMR	TMR
FG	250	725	177	46
FGHA	51	646	0	0
FGGSHA	69	150	22	0
GS	180	6508	6277	2089
GSHA	35	673	476	83
GSMS	0	76	196	41
GSMSHA	13	371	442	202
MS	98	2091	6553	1583
MSHA	0	105	55	42
MSGST	0	50	111	2
MSGSFG	8	128	0	0
CLGMSHA	23	1298	1165	335
CLMS	0	322	97	10
ALGSHAMS	16	506	128	0
ALMS	0	16	112	34
ALGS	0	41	127	5
HA	124	2532	373	60
OTHER	46	45	23	8

*FG: fresh grass; HA: hay; GS: grass silage; MS: maize silage; ST: straw; CL: clover; AL: alfalfa

[¶]FOR: pure forage diet; SEP: forage diet with separately fed concentrate; PMR: partial mixed ration; TMR: total mixed ration

Tabelle 2 suppl.: Datenverteilung der Grundfuttertypen innerhalb des Genotyps.

Forage type*	Genotype [¶]						
	FV	FV×RH6.25	FV×RH12.5	FV×RH25	FV×RH5075	HF	BS
FG	289	122	46	79	57	305	300
FGHA	164	80	15	9	8	52	369
FGGSHA	65	31	3	8	4	58	72
GS	4209	2684	985	1155	807	1639	3575
GSHA	301	208	61	65	67	162	403
GSMS	50	43	11	17	22	107	63
GSMSHA	350	173	53	91	48	80	233
MS	2437	1454	546	598	633	2628	2029
MSHA	24	1	0	0	4	8	165
MSGST	68	26	11	16	11	31	0
MSGSFG	13	9	10	7	3	1	93
CLGMSHA	695	449	155	71	336	565	550
CLMS	213	72	10	5	35	94	0
ALGSHAMS	153	180	85	36	49	126	21
ALMS	37	64	34	13	11	3	0
ALGS	44	39	23	23	7	37	0
HA	769	312	105	168	77	276	1382
OTHER	61	22	3	4	1	0	31

*FG: fresh grass; HA: hay; GS: grass silage; MS: maize silage; ST: straw; CL: clover; AL: alfalfa

[¶]FV: Fleckvieh; RH: Red Holstein; 6.25 – 5075: average proportion of Red Holstein; FV×RH5075: Fleckvieh with an average proportion of 68% Red Holstein; HF: Holstein Friesian; BS: Brown Swiss

Tabelle 3 suppl.: Datenverteilung der Wechselwirkung Genotyp × Laktationszahl.

Genotype*	Parity			
	1	2	3+4	≥5
FV	2307	1967	3055	2613
FV×RH6.25	2105	1280	1547	1037
FV×RH12.5	733	454	604	365
FV×RH25	728	444	712	481
FV×RH5075	541	491	600	548
HF	1844	1522	1773	1033
BS	2598	2227	2574	1887

* FV: Fleckvieh; RH: Red Holstein; 6.25 – 5075: average proportion of Red Holstein; FV×RH5075: Fleckvieh with an average proportion of 68% Red Holstein; HF: Holstein Friesian; BS: Brown Swiss

Tabelle 4 suppl.: Datenverteilung der Wechselwirkung Genotyp × Laktationsstadium.

Genotype*	Stage of lactation (Day in milk, DIM)											
	17	43	71	98	127	154	182	210	238	266	294	321
FV	758	966	951	961	926	911	896	904	864	801	652	352
FV×RH6.25	442	606	594	562	567	535	541	496	566	470	383	207
FV×RH12.5	179	217	229	202	203	196	197	192	188	161	120	72
FV×RH25	209	241	244	227	225	211	205	210	197	183	136	77
FV×RH5075	171	214	204	198	200	186	212	182	188	178	152	95
HF	476	587	582	564	559	573	568	521	520	511	422	289
BS	735	926	859	880	890	789	841	797	751	746	614	458
Parity												
1	814	1087	1066	1012	971	987	998	958	958	874	686	445
2	661	813	767	821	816	719	765	723	738	663	561	338
3+4	862	1067	1033	990	1032	964	990	958	912	890	729	438
≥5	633	790	797	771	751	731	707	663	666	623	503	329

* FV: Fleckvieh; RH: Red Holstein; 6.25 – 5075: average proportion of Red Holstein; FV×RH5075: Fleckvieh with an average proportion of 68% Red Holstein; HF: Holstein Friesian; BS: Brown Swiss

Tabelle 5 suppl.: LS-Means der Wechselwirkung Genotyp × Laktationsstadium für Laktationstag, Lebendmasse, Milchleistung und BCS.

Trait	Unit	Genotype	Stage of lactation (months post partum)											
			1	2	3	4	5	6	7	8	9	10	11	12
Day in milk*	d	FV	18	43	70	98	127	155	183	211	239	266	293	322
		FV×RH6.25	18	42	71	98	127	155	183	210	238	267	293	321
		FV×RH12.5	18	42	71	99	127	155	182	210	239	267	293	319
		FV×RH25	16	43	72	98	127	155	182	210	238	267	295	320
		FV×RH5075	17	43	71	99	127	155	183	211	239	266	294	324
		HF	17	43	71	99	127	154	183	211	239	266	295	321
		BS	17	43	71	98	127	155	182	211	238	266	294	322
Body weight	kg	FV	700	691	696	700	706	711	721	730	739	748	760	766
		FV×RH6.25	709	698	700	709	711	716	726	734	745	758	769	772
		FV×RH12.5	696	697	706	705	709	718	727	734	754	753	771	765
		FV×RH25	700	693	697	703	704	718	725	734	752	753	764	
		FV×RH5075	689	673	680	684	692	693	701	713	720	734	747	750
		HF	644	632	637	640	644	653	659	670	678	688	702	703
		BS	633	627	626	632	636	638	645	652	661	671	677	686
ECM	kg/d	FV	32.6	32.2	31.4	30.0	28.6	27.6	26.3	25.4	23.8	22.0	20.5	20.3
		FV×RH6.25	33.0	32.8	31.8	30.3	29.5	27.9	26.8	25.5	23.7	21.9	20.5	20.0
		FV×RH12.5	31.6	33.5	33.0	30.7	29.3	27.8	26.9	24.8	23.4	21.3	19.5	20.7
		FV×RH25	33.3	33.2	32.6	31.3	29.8	28.9	27.2	26.3	24.5	23.2	21.3	21.1
		FV×RH5075	35.2	35.9	34.6	33.0	30.9	30.5	29.3	27.7	26.4	24.1	22.6	21.7
		HF	35.3	35.2	34.0	33.2	31.9	30.2	28.9	27.5	25.8	24.3	22.7	21.5
		BS	32.7	32.0	30.7	29.4	28.4	26.9	26.1	24.8	23.7	22.3	21.6	20.1
BCS	Points 1-5	FV	3.39	3.31	3.26	3.30	3.33	3.33	3.41	3.45	3.51	3.52	3.61	3.64
		FV×RH6.25	3.38	3.25	3.23	3.24	3.28	3.31	3.35	3.41	3.46	3.56	3.56	3.61
		FV×RH12.5	3.41	3.24	3.26	3.23	3.25	3.29	3.37	3.41	3.48	3.47	3.57	3.59
		FV×RH25	3.32	3.14	3.15	3.14	3.08	3.19	3.23	3.22	3.32	3.37	3.33	3.35
		FV×RH5075	3.07	2.88	2.87	2.90	2.96	2.95	2.99	3.06	3.10	3.15	3.29	3.26
		HF	2.73	2.50	2.46	2.45	2.46	2.47	2.56	2.62	2.68	2.73	2.82	2.83
		BS	2.95	2.83	2.76	2.79	2.78	2.81	2.85	2.91	2.90	2.98	2.99	3.01

*LS-means of day in milk of 28-day classes 1–12; ECM: energy corrected milk (GfE 2001); BCS: Body condition score

FV: Fleckvieh; RH: Red Holstein; 6.25–5075: average proportion of Red Holstein; FV×RH5075: Fleckvieh with an average proportion of 68% Red Holstein; HF: Holstein Friesian; BS: Brown Swiss
Ledinek et al. (2019a,b)

Tabelle 6 suppl.: LS-Means der Wechselwirkung Genotyp × Laktationsstadium der Milchinhaltsstoffe.

Trait	Unit	Genotype	Stage of lactation (months post partum)											
			1	2	3	4	5	6	7	8	9	10	11	12
Milk fat	%	FV	4.23	3.93	3.89	3.92	3.99	4.08	4.18	4.29	4.36	4.47	4.58	4.60
		FV×RH6.25	4.35	3.98	3.91	4.01	4.09	4.15	4.27	4.34	4.43	4.53	4.64	4.69
		FV×RH12.5	4.26	3.90	4.01	3.94	4.05	4.04	4.18	4.26	4.34	4.48	4.53	4.72
		FV×RH25	4.40	3.96	3.94	4.02	4.08	4.11	4.22	4.32	4.40	4.50	4.71	4.70
		FV×RH5075	4.41	3.91	3.89	3.95	3.99	4.05	4.17	4.30	4.36	4.47	4.49	4.64
		HF	4.40	3.86	3.81	3.79	3.90	3.94	4.01	4.12	4.21	4.31	4.30	4.41
		BS	4.26	3.87	3.84	3.92	3.99	4.02	4.13	4.17	4.21	4.28	4.38	4.47
Milk protein	%	FV	3.33	3.13	3.22	3.34	3.45	3.51	3.56	3.63	3.69	3.76	3.84	3.88
		FV×RH6.25	3.38	3.14	3.25	3.38	3.46	3.53	3.60	3.65	3.71	3.78	3.89	3.94
		FV×RH12.5	3.33	3.12	3.26	3.36	3.47	3.54	3.60	3.67	3.73	3.77	3.86	3.90
		FV×RH25	3.43	3.13	3.25	3.38	3.46	3.52	3.58	3.64	3.68	3.79	3.86	3.92
		FV×RH5075	3.33	3.04	3.14	3.27	3.38	3.44	3.48	3.54	3.64	3.69	3.75	3.90
		HF	3.26	2.96	3.05	3.16	3.27	3.32	3.35	3.45	3.51	3.57	3.63	3.67
		BS	3.33	3.11	3.21	3.35	3.43	3.48	3.53	3.58	3.62	3.70	3.76	3.84
Milk lactose	%	FV	4.79	4.82	4.81	4.78	4.76	4.73	4.70	4.70	4.69	4.69	4.65	4.63
		FV×RH6.25	4.79	4.84	4.82	4.80	4.76	4.74	4.70	4.70	4.68	4.67	4.62	4.63
		FV×RH12.5	4.77	4.82	4.80	4.77	4.74	4.73	4.70	4.65	4.65	4.65	4.61	4.63
		FV×RH25	4.77	4.84	4.82	4.80	4.76	4.74	4.71	4.71	4.71	4.68	4.65	4.66
		FV×RH5075	4.75	4.83	4.82	4.80	4.77	4.74	4.72	4.70	4.67	4.67	4.65	4.64
		HF	4.74	4.83	4.82	4.81	4.78	4.76	4.71	4.70	4.68	4.66	4.64	4.62
		BS	4.77	4.84	4.83	4.82	4.79	4.76	4.74	4.71	4.71	4.69	4.67	4.64

FV: Fleckvieh; RH: Red Holstein; 6.25–5075: average proportion of Red Holstein; FV×RH5075: Fleckvieh with an average proportion of 68% Red Holstein; HF: Holstein Friesian; BS: Brown Swiss
Ledinek et al. (2019b)

Tabelle 7 suppl.: LS-Means der Wechselwirkung Genotyp × Laktationsstadium für Futteraufnahme, NDF-Aufnahme und Kraftfutteranteil.

Trait	Unit	Genotype	Stage of lactation (months post partum)											
			1	2	3	4	5	6	7	8	9	10	11	12
DMI	kg DM/d	FV	19.75	20.76	21.11	20.89	20.45	20.10	19.69	19.41	19.01	18.61	18.38	18.47
		FV×RH6.25	19.98	21.01	21.32	21.04	20.73	20.21	19.84	19.47	19.01	18.60	18.40	18.31
		FV×RH12.5	19.55	21.26	21.51	21.15	20.75	20.26	20.03	19.46	19.20	18.44	18.26	18.56
		FV×RH25	19.92	21.26	21.61	21.37	20.95	20.86	20.26	20.00	19.65	19.29	18.83	18.84
		FV×RH5075	20.53	21.74	22.10	21.84	21.52	21.32	20.95	20.57	20.31	19.82	19.68	19.40
		HF	20.02	21.47	21.85	21.99	21.65	21.34	21.04	20.70	20.40	20.11	20.05	19.71
		BS	19.55	20.83	20.96	20.74	20.48	20.07	19.84	19.52	19.33	19.06	19.01	18.72
DMI	g/kg BW ^{0.75}	FV	144.6	153.3	155.1	153.0	148.9	145.7	141.3	138.1	134.1	130.2	127.1	127.1
		FV×RH6.25	145.2	154.4	156.4	152.9	150.5	146.0	142.0	138.2	133.4	128.9	126.3	125.1
		FV×RH12.5	143.9	156.5	156.7	154.4	151.1	146.0	143.1	138.1	133.7	128.5	125.0	127.5
		FV×RH25	145.7	156.7	158.5	155.8	152.7	149.8	144.5	141.5	136.5	133.9	129.3	131.1
		FV×RH5075	152.7	164.6	166.1	163.5	159.9	158.3	154.2	149.5	146.6	141.2	138.1	136.1
		HF	157.4	170.9	173.0	173.4	170.0	165.8	162.4	157.9	154.2	150.4	147.5	145.0
		BS	154.9	166.1	167.1	164.3	161.7	158.1	155.1	151.4	148.5	144.9	143.7	140.3
NDF intake	g/kg BW	FV	10.7	11.2	11.3	11.2	11.0	10.8	10.6	10.4	10.2	10.0	9.9	9.9
		FV×RH6.25	10.8	11.3	11.4	11.2	11.0	10.8	10.6	10.4	10.2	9.9	9.8	9.8
		FV×RH12.5	10.8	11.5	11.4	11.3	11.1	10.8	10.6	10.3	10.1	10.1	9.8	9.9
		FV×RH25	11.0	11.5	11.7	11.5	11.3	11.0	10.7	10.6	10.2	10.1	10.0	10.1
		FV×RH5075	11.4	12.2	12.3	12.2	11.9	11.9	11.6	11.3	11.1	10.8	10.5	10.5
		HF	12.0	12.8	12.9	13.0	12.8	12.5	12.3	12.0	11.7	11.5	11.3	11.2
		BS	11.8	12.4	12.5	12.4	12.3	12.1	11.9	11.7	11.6	11.3	11.3	11.1
Concentrate	% of DM	FV	30.2	32.9	33.2	32.4	30.8	29.5	27.9	26.4	24.2	21.6	18.8	18.4
		FV×RH6.25	30.4	32.9	33.5	32.2	31.4	29.5	28.2	26.3	23.3	20.5	18.3	16.7
		FV×RH12.5	29.0	33.0	32.8	32.0	31.5	28.7	28.4	27.1	24.7	20.1	17.5	18.3
		FV×RH25	28.8	32.2	32.9	31.8	31.0	30.8	28.6	27.4	25.8	23.1	18.7	18.7
		FV×RH5075	30.4	32.5	32.6	31.6	31.5	30.7	29.1	28.0	26.4	24.1	22.6	20.5
		HF	30.6	33.4	33.2	33.1	32.1	31.2	29.9	28.6	27.6	26.2	24.5	23.4
		BS	31.2	34.5	33.7	32.3	31.1	29.5	27.9	26.3	25.0	22.7	21.2	19.6

DMI: dry matter intake; DM: dry matter; feed intake is predicted; NDF: neutral detergent fibre; BW: body weight

FV: Fleckvieh; RH: Red Holstein; 6.25–5075: average proportion of Red Holstein; FV×RH5075: Fleckvieh with an average proportion of 68% Red Holstein; HF: Holstein Friesian; BS: Brown Swiss

Ledinek et al. (2019a,b)

Tabelle 8 suppl.: LS-Means der Wechselwirkung Genotyp × Laktationsstadium für Energiebilanz und Effizienzmerkmale.

Trait	Unit	Genotype	Stage of lactation (months post partum)											
			1	2	3	4	5	6	7	8	9	10	11	12
Energy balance	MJ NEL/d	FV	-16.68	-7.35	-2.46	-0.07	0.75	0.70	1.04	0.77	1.27	1.91	2.37	3.12
		FV×RH6.25	-16.66	-7.85	-2.20	-0.23	-0.12	0.42	0.38	0.70	1.11	1.41	1.74	2.51
		FV×RH12.5	-15.30	-8.55	-5.62	-1.17	0.38	0.54	1.13	3.03	3.27	1.26	2.87	1.51
		FV×RH25	-18.41	-7.46	-3.08	-1.35	0.43	1.84	2.18	1.73	2.95	2.55	1.16	4.67
		FV×RH5075	-19.34	-12.33	-5.96	-3.07	1.36	0.80	1.07	2.60	3.55	4.61	6.65	6.60
		HF	-21.61	-10.43	-4.02	-0.73	0.74	3.51	4.38	5.50	8.02	8.98	11.88	12.88
		BS	-15.21	-3.01	1.76	3.86	4.73	6.12	6.10	6.82	7.63	8.12	8.39	10.03
Body weight efficiency	kg ECM/kg BW ^{0.75}	FV	0.238	0.237	0.230	0.219	0.208	0.200	0.189	0.181	0.168	0.154	0.142	0.141
		FV×RH6.25	0.239	0.240	0.233	0.220	0.214	0.202	0.192	0.181	0.167	0.152	0.142	0.137
		FV×RH12.5	0.232	0.245	0.239	0.224	0.213	0.200	0.192	0.176	0.163	0.148	0.134	0.143
		FV×RH25	0.242	0.244	0.238	0.228	0.217	0.208	0.194	0.187	0.171	0.161	0.147	0.148
		FV×RH5075	0.260	0.270	0.259	0.247	0.229	0.226	0.215	0.201	0.191	0.172	0.158	0.152
		HF	0.275	0.279	0.268	0.261	0.250	0.234	0.223	0.209	0.195	0.182	0.167	0.158
		BS	0.258	0.254	0.244	0.232	0.223	0.211	0.204	0.192	0.182	0.170	0.163	0.151
Feed efficiency	kg DMI/kg ECM	FV	1.642	1.535	1.471	1.422	1.382	1.360	1.319	1.292	1.236	1.163	1.095	1.079
		FV×RH6.25	1.637	1.544	1.476	1.427	1.408	1.367	1.336	1.296	1.232	1.157	1.096	1.073
		FV×RH12.5	1.594	1.551	1.509	1.434	1.393	1.354	1.326	1.259	1.204	1.140	1.049	1.100
		FV×RH25	1.649	1.540	1.487	1.450	1.406	1.373	1.326	1.305	1.235	1.187	1.119	1.109
		FV×RH5075	1.688	1.623	1.544	1.490	1.413	1.410	1.381	1.329	1.280	1.205	1.134	1.101
		HF	1.734	1.613	1.533	1.491	1.451	1.398	1.361	1.317	1.256	1.201	1.126	1.087
		BS	1.668	1.525	1.452	1.403	1.371	1.325	1.300	1.254	1.208	1.151	1.116	1.053
Energy efficiency	MJ LE/MJ NEL	FV	0.799	0.742	0.710	0.687	0.670	0.663	0.646	0.636	0.614	0.583	0.553	0.545
		FV×RH6.25	0.797	0.745	0.710	0.689	0.682	0.666	0.654	0.639	0.613	0.581	0.554	0.547
		FV×RH12.5	0.778	0.747	0.728	0.695	0.675	0.662	0.649	0.619	0.597	0.576	0.535	0.557
		FV×RH25	0.806	0.743	0.717	0.702	0.682	0.666	0.647	0.641	0.610	0.592	0.568	0.562
		FV×RH5075	0.820	0.783	0.745	0.721	0.684	0.685	0.673	0.651	0.629	0.600	0.568	0.554
		HF	0.842	0.777	0.739	0.720	0.704	0.678	0.664	0.646	0.618	0.594	0.560	0.543
		BS	0.812	0.733	0.699	0.678	0.665	0.645	0.635	0.617	0.597	0.573	0.558	0.529

NEL: net energy for lactation; ECM: energy corrected milk (GfE 2001); DMI: dry matter intake; feed and energy intake are predicted; BW^{*}: metabolic body weight; LE: energy in milk

FV: Fleckvieh; RH: Red Holstein; 6.25–5075: average proportion of Red Holstein; FV×RH5075: Fleckvieh with an average proportion of 68% Red Holstein; HF: Holstein Friesian; BS: Brown Swiss; (Ledinek et al. 2019a,b)