Evaluation of Herbage Intake Estimation Methods for Dairy Cattle Grazing on Semi-Extensive Pastures

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The XXIV International Grassland Congress / XI International Rangeland Congress (Sustainable Use of Grassland and Rangeland Resources for Improved Livelihoods) takes place virtually from October 25 through October 29, 2021.

Proceedings edited by the National Organizing Committee of 2021 IGC/IRC Congress
Published by the Kenya Agricultural and Livestock Research Organization

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Key words: herbage intake estimation; grazing; dairy cattle

Abstract
Available empirical and mechanistic models to estimate total dry matter intake (DMI) and pasture dry matter intake (PDMI) of grazing lactating dairy cows have mainly been developed under intensive grazing conditions. The objective was to evaluate the adequacy of such existent models for use under semi-extensive grazing conditions, characterised by semi-natural grassland and less intensive resource use. Feed intake of lactating cows was measured on three commercial organic dairy farms in South Germany during one or two 6-d-periods/farm in 2019. Each period, DMI was determined in 10 or 20 cows per farm from their daily faecal output measured using titanium dioxide as marker and the apparent total tract digestibility of ingested organic matter derived from faecal crude protein concentration. PDMI was then calculated by subtracting weighed DMI of supplement feeds from total DMI. Further, individual milk yield and body weight were recorded, and samples of milk, pasture forage, supplement feed, and faeces were taken. For further analysis, means of observed values per farm and period ($n = 7$) were used, resulting in a diverse dataset of grazing systems differing in supplement feeding, daily pasture allocation, cow breed, and PDMI. Two semi-mechanistic PDMI models and six empirical and two semi-mechanistic models to predict total DMI were evaluated by their Mean Squared Error of Prediction, Relative Prediction Error (RPE) and Concordance Correlation Coefficient. One PDMI model produced acceptable (RPE < 20% of mean observed PDMI), and four total DMI models yielded satisfactory (RPE < 10%) prediction accuracy, however yet at a moderate precision (greatest Pearson correlation coefficient = 0.73). To further specify the grazing conditions under which the models reach both, satisfactory precision and accuracy, and due to the low number of observations, data of the present study will be complemented with data gathered on more farms in Southwest Germany in 2020.

Introduction
Reliable estimates of feed intake are a key factor within ruminant research and farming practices. In a grazing context, however, quantifying actual pasture dry matter intake (PDMI) of cows is particularly challenging. Thus, several estimation methods have been established. Quantifying the biomass removal from paddocks allows only for rough estimates on herd and paddock level, whereas using external and internal markers to quantify total faecal output and diet digestibility in order to estimate total feed intake of cows is labour- and cost-intensive. Alternatively, mathematical models have been developed to predict feed intake of cows from animal, feed, and management characteristics. These models can be applied in research, but also as integral part of decision-support tools in grazing and feeding management (Tedeschi et al. 2019). Since these models were predominantly developed and validated under or for intensive grazing conditions, the question arises whether these models can also adequately predict PDMI of cows in semi-extensive grazing-based production systems, such as organic farming systems where semi-natural, permanent grassland is used. It was, thus, hypothesised that existing models are not able to adequately predict the PDMI of grazing dairy cows under semi-extensive production conditions, due to differences in cattle breed, animal performance and feed intake level, pasture herbage availability, botanical composition of the pasture vegetation, and the type and intensity of supplement feeding. Therefore, the objective of the present study was to evaluate the adequacy of existing models for estimating PDMI and total DMI of lactating dairy cows grazing under semi-extensive production conditions, using data gathered on organic dairy farms with semi-natural, permanent pastures.

Methods and Study Site
Model selection
A literature research was conducted to identify existing models to predict PDMI and total DMI of cows. Two semi-mechanistic models to predict PDMI (GrazeSim: Vazquez and Smith 2001; e-cow: Baudracco et al. 2012), as well as six empirical (AFRC: Vadiveloo and Holmes 1979; Cornell: Fox et al. 1992; De Souza: de Souza et al. 2019; Gruber: DLG 2006; NRC: NRC 2001; Sauvant: Sauvant et al. 2014) and two semi-mechanistic models to predict total DMI (Conrad: Conrad et al. 1964; Mertens I: Mertens et al. 1987) were selected. It was further tested, if applying a greater intake capacity to the Mertens' model improves its

modelling adequacy (Mertens II: with an intake capacity of 1.65% instead 1.30% x bodyweight), because a higher intake capacity was observed by Vazquez and Smith (2001) with animals offered a high pasture allowance and forage supplementation. For the models GrazeSim, e-cow, Mertens I and Mertens II, the German animal nutrition system was used to determine metabolisable energy requirements (GfE, 2001).

Data collection and dataset

From May to September 2019, experiments were conducted on three commercial organic farms in South Germany. Farms were visited once (farm 1) or twice (farm 2 and 3), to cover early and late summer grazing conditions. In each period on farm 2, two different supplementation treatments were tested. Per farm or treatment, 10 lactating dairy cows were sampled. They had between 8 to 20 h/d of access to species-rich, semi-natural pastures. Upon visual inspection of the aboveground biomass, the pasture swards comprised on average (± standard deviation) 49 (± 22) % grasses, 24 (± 19) % clover, and 28 (± 20) % herbs other than clover across all farms and the whole grazing season. Cows were supplemented with grass silage, grass hay, cut fresh clover-grass mixture, and/or concentrate feeds. Individual animal were noted per period. During five days of adaptation and six days of sampling, cows daily received 26 g titanium dioxide (TiO_2) in two equal dosages in early summer and 28 g TiO_2 in late summer. During sampling periods, faecal grab samples were taken from the cow's rectum daily. Samples of offered and refused feed were taken daily, and intake of supplemented feed by the entire herd or treatment group (farm 2) was measured by weighing total offered feed and refusals. Once per experimental period, pasture vegetation on grazed paddocks were sampled. The aboveground herbage mass was estimated by manual harvest in three 1-m^2-plots per paddock. Faecal samples were analysed for crude protein (CP), organic matter (OM), and TiO_2. Feed samples were analysed for dry matter (DM), OM, CP, neutral detergent fibre (NDF), acid detergent fibre (ADF), and metabolisable energy (ME). Milk yield was measured and samples taken daily, alternating between morning or evening milking, and analysed for fat and protein. Body weight of cows was estimated once per period with a calibrated measuring tape. Total organic matter intake (OMI) was calculated from daily faecal excretion and apparent total tract OM digestibility (DOM) of ingested feed. Daily faecal OM output was determined from dosage and faecal concentration of TiO_2 assuming a recovery in faeces of 100% (Glindemann et al. 2009), while DOM was estimated from faecal CP concentration (Lukas et al. 2005). Mean OMI on pasture (kg/animal and d) per farm, period and treatment was derived as difference between mean OMI and herd supplement OMI. Total DMI and PDMI were then calculated using the mean OM concentration of the ingested diet or pasture herbage, respectively.

Statistical analysis

The models were used to estimate DMI and PDMI on individual-cow basis. For model evaluation, the mean predicted DMI and PDMI per farm, period and treatment (n = 7) were compared against mean observed DMI and PDMI. The Mean Squared Error of Prediction (MSEP) and Relative Prediction Error (RPE) were used to evaluate the accuracy of the models. The RPE was classified according to Fuentes-Pila et al. (1996), who assumed that the prediction accuracy is 'satisfactory' with an RPE < 10%, 'acceptable' between 10% and 20%, and 'not acceptable' with an RPE > 20%. The MSEP was further partitioned to evaluate whether deviations from the observed values were related to systematic errors in the models, i.e. prediction bias and line bias, or to random errors caused by variation in the observed data, i.e. random error (Fuentes-Pila et al. 1996). Additionally, the Concordance Correlation Coefficient (CCC) was used to evaluate model adequacy on a scale from 0 to 1, where 1 signifies perfect concordance between observed and predicted values. The CCC is a product of the Pearson correlation coefficient (r) and bias correction factor (cb), which assess precision and accuracy, respectively (Tedeschi 2006).

Results

The data set covered different grazing management systems (n = 7), seasons (early and late summer), types and intensities of supplement feeds offered, and herbage availabilities on pastures. Animals differed in breeds (Simmental, Brown Swiss, and German Holstein), days in milk (126–185d), and parity (3–5). Their mean (± standard deviation) observed PDMI and DMI was 13.0 (± 3.5) and 19.2 (± 1.6) kg DM/d and they produced on average 21.4 (± 2.7) kg milk/d with mean concentrations of fat and protein of 3.8 (± 0.20) and 3.2 (± 0.21) g/100 g milk, respectively. Daily supplementation ranged from 0.5 to 10.8 kg DM.

Among the two PDMI models, only e-cow yielded an acceptable RPE (17.4%) and a high CCC (0.65), with high prediction precision (r = 0.65) and accuracy (cb = 0.90) (Table 1). The RPE of GrazeSim (25.3%) was not satisfactory. Its CCC (0.46), however, implied a moderate prediction adequacy, which was mainly attributed to its high cb (0.99; i.e. high accuracy). All models to predict total DMI except the AFRC model yielded acceptable predictions (RPE < 20%). A satisfactory prediction accuracy was achieved by the models Gruber, Cornell, Mertens I, and Mertens II with a RPE < 10% and a mean bias of 0.3–1.0 kg DM/d, indicating a general overprediction of DMI. The most adequate model to predict total DMI was Mertens II, as it yielded the lowest RPE (6.8%) and greatest CCC (0.58) among the nine tested DMI models. The greatest proportion of MSPE for model Mertens II (89.6%) constitutes the random variation in the observed data.

Table 1. Statistical evaluation of empirical and semi-mechanistic models to predict total daily dry matter intake (DMI) and of semi-mechanistic models to predict pasture dry matter intake (PDMI) of lactating dairy cows grazing on semi-natural, permanent grassland

			Partitioning of MSEP, %						
	MB, kg DM/d [4]	**MSEP** [5]	Prediction bias	Line bias	Random error	**RPE, %** [6]	**CCC** [7]	**r** [8]	**C_b** [9]
Empirical models to predict DMI [1]									
AFRC	4.6	22.9	91.4	0.4	8.1	25.0	0.07	0.48	0.15
Cornell	0.7	2.1	23.8	0.0	76.2	7.6	0.43	0.57	0.77
De Souza	-0.6	8.9	3.7	71.6	24.7	15.5	-0.28	-0.30	0.92
Gruber	0.9	2.9	25.7	5.0	69.3	8.8	0.33	0.42	0.78
NRC	-0.7	4.4	11.5	35.1	53.4	11.0	0.12	0.14	0.91
Sauvant	1.6	7.3	33.9	37.2	28.9	14.1	0.26	0.35	0.73
Semi-mechanistic models to predict DMI [2]									
Conrads	-1.9	5.9	58.9	20.7	20.4	12.6	0.48	0.71	0.67
Mertens I	1.0	2.7	36.8	6.5	56.6	8.6	0.50	0.60	0.82
Mertens II	0.3	1.7	4.8	5.7	89.6	6.8	0.58	0.60	0.96
Semi-mechanistic models to predict PDMI [3]									
GrazeSim	0.4	10.8	1.8	20.9	77.3	25.3	0.46	0.46	0.99
e-cow	-0.1	5.1	0.3	2.1	97.6	17.4	0.65	0.73	0.90

[1]AFRC (Vadiveloo and Holmes 1979), Cornell (Fox et al. 1992), De Souza (De Souza et al. 2019), Gruber (DLG 2006), NRC (NRC 2001), Sauvant (Sauvant et al. 2014) [2]Conrad (Conrad et al. 1964), Mertens (Mertens et al. 1987, using metabolisable energy requirements according to GfE (2001)) 3GrazeSim (Vazquez and Smith 2001, using metabolisable energy requirements according to GfE (2001)), e-cow (Baudracco et al. 2012, metabolisable energy requirements according to GfE (2001)) [5]CCC: Concordance correlation coefficient [4]MB: Mean bias [5] MSEP: Mean squared error of prediction [6]RPE: relative prediction error, % of observed mean PDMI and DMI [7]CCC: Concordance correlation coefficient [8]*r*: Pearson correlation coefficient [9]C_b: bias correction factor

Discussion

It was hypothesised that existing empirical and mechanistic models were unable to adequately predict PDMI of lactating dairy cows under semi-extensive production conditions. A low concordance between observed PDMI and PDMI predicted by models developed under intensive production conditions was expected, as grazing under semi-extensive conditions was assumed to entail differences, e.g. in supplementation intensity and pasture herbage quality and mass offered. Results, in contrast, show that one model, i.e. e-cow, yielded acceptable predictions (RPE < 20%) for the PDMI of lactating cows under semi-extensive grazing conditions. The differences between observed and predicted values, however, ranged from -3.4 to 3.6 kg DM/d. Therefore, no satisfactory prediction accuracy was achieved by this model. One reason for the overestimation of PDMI by e-cow for some observations could be that the model primarily considers grazing systems where pasture allocation, i.e. daily pasture mass offered to the animal (kg DM), is not a limiting factor. This means, the model assumes that pasture allocation is equal or greater than the potential DMI of the cows; the potential DMI being an intermediate model variable of e-cow, estimated based on lactation stage, energy requirements and intake capacity. In the dataset used for the present study, however, this pre-requisite is not met for every observation. For these observations, e-cow predicted a PDMI, irrespective of supplementation, that was up to 60% greater than the observed pasture allocation. Further, e-cow contains empirical equations based on data where cows were grazing lucerne- or ryegrass-dominant swards, and which were supplemented with hay, silage or concentrate. Our dataset, however, mainly contained grazing systems where cows were grazing on clover- and herb-rich pastures, and were supplemented with freshly cut forage in barn.

Further, six models were tested for their ability to predict the total DMI of grazing lactating dairy cows. With exception of the AFRC model, RPE were low and similar to the RPE determined by Jensen et al. (2015) who evaluated five DMI models (among these, also NRC and Gruber) with a Scandinavian dataset of barn-fed dairy cows (n = 94 treatment means, RPE = 5–4%). Hence, the models were able to predict total DMI of grazing dairy cows with a similar accuracy as of barn-fed animals, which is another evidence for rejecting the hypothesis of this study. The greatest prediction adequacy (i.e., lowest RPE and highest CCC) was achieved by the Mertens II model, which was derived from the original Mertens I model by assuming a greater feed intake capacity of grazing cows as compared to barn-fed cows, for which the Mertens I model was developed. The Mertens II model had not only a greater CCC and a lower RPE than the Mertens I model, but also a substantially lower share of systematic error of the MSEP (10.5 vs. 43.3%), indicating that the model structure was improved by the modification. A high adequacy was actually expected of the predictions by the Gruber model, because it was developed based on data from German, Austrian, and Swiss stall-fed dairy cows. This model, however, relies on empirical equations, primarily based on the observed relation between DMI and the lactation stage of barn-fed dairy cows. Hence, the superior prediction adequacy of Mertens II is likely a result of its semi-mechanistic structure, which estimates total DMI based on the animal's energy requirements and intake capacity, as well as the nutritional quality of offered feeds, including the pasture herbage.

Contrary to the hypothesis, several models were identified that predicted PDMI with an acceptable, and total DMI with a satisfactory prediction accuracy. Among all tested models, however, precision was yet low (greatest $r = 0.73$) indicating that the models were unable to adequately predict the DMI for all grazing systems observed in this study. Considering the great variability between the observed farms and the low number of observations ($n = 7$), this highlights the need to further specify the conditions under which the models yield both, a high precision and accuracy. The present dataset will therefore be complemented with data gathered from more farms in Southwest Germany in 2020.

Acknowledgements

This work was part of the CORE Organic Plus project GrazyDaiSy, which was supported by funds of the Federal Ministry of Food and Agriculture (funding code 2817OE011). We further want to acknowledge the support provided by Sigrid Griese (Bioland Beratung GmbH), Sören Binder (Bioland e. V.), Corinna Nieland (Demeter e.V.), Bettina Egle (Demeter Beratung e.V.), and the farmers involved in this study. The scholarship for Ms. Perdana-Decker was provided by the Deutsche Bundesstiftung für Umwelt.

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