Livestock Science 254 (2021) 104768

Contents lists available at ScienceDirect

Livestock Science

journal homepage: www.elsevier.com/locate/livsci

# Effects of an all-herbage versus a concentrate-supplemented ration on productivity, body condition, medical treatments and reproduction in two Holstein cow types under organic conditions.

F. Schori *, A. Münger

*Agroscope, Ruminant Research Group, Tioleyre 4, 1725 Posieux, Switzerland*

## HIGHLIGHTS

- A rare study investigating the effects of a true all-herbage ration in dairy cows.
- All herbage vs concentrate supplemented rations were fed to two different cow types.
- Results include production, body condition, medical treatments and reproduction.
- Cow type seems to be more important than concentrate supplementation.
- Low-input and all-herbage feeding systems are viable using suited dairy cows.

## ARTICLE INFO

*Keywords:*
All-herbage
Dairy cow
Concentrate
Holstein
Pasture
Organic

## ABSTRACT

The effects of an all-herbage ration on dairy cows, as compared to a concentrate-supplemented herbage-based ration, were investigated over three years. In total, 138 lactation records of 92 Holstein cows, of which 67 were of Swiss (HCH) and 25 were of New Zealand origin (HNZ), were taken into account. Concurrently, the all-herbage ration (AH) was compared to a treatment in which 750 kg of concentrate (C750) were offered during the first 300 days in milk. During the winter feeding period, hay was fed, and during the grazing season, herbage was grazed. With this concentrate supplementation, dairy cows produced, per standard lactation (305d), more milk, energy-corrected milk (ECM), milk fat, milk protein, lactose, ECM per body weight (BW) and ECM per unit of metabolic body size. In addition, the concentrate-supplemented cows showed slightly higher BW and body condition scores (BCS). The milk content in terms of fat, protein, lactose and urea, as well as the somatic cell counts (SCC), remained unchanged with concentrate supplementation. The HCH produced more milk and lactose. Due to the lower fat, protein and lactose content in the milk of the HCH, no significant differences were found concerning ECM, milk fat and milk protein yield between the two cow types. Because the HCH were heavier, they produced less ECM per BW and unit of metabolic body size than the HNZ. Furthermore, the HCH received lower average BCS ratings than the HNZ. Finally, both cow types showed similar values regarding milk urea content and SCC. No interactions between the concentrate supplementation and cow type factors were found. No significant differences in the number of medical treatments and reproduction traits were noted between the concentrate treatments, except for a trend towards fewer re-calvings after standard lactation with the all-herbage ration. In contrast, differences occurred between the two cow types. The HCH received more medical treatments than the HNZ for fertility issues and in total. Fewer medical treatments were necessary for claw and leg issues for the HCH compared to the HNZ. In contrast, the calving intervals of the HCH were significantly longer, and the intervals between calving and both first service and conception tended to be longer. All-herbage rations remain feasible today, but dairy cows adapted to cope with adversities commonly associated with low-input feeding systems might be advantageous to use.

* Corresponding author.
*E-mail address:* fredy.schori@agroscope.admin.ch (F. Schori).

https://doi.org/10.1016/j.livsci.2021.104768
Received 1 April 2021; Received in revised form 26 October 2021; Accepted 7 November 2021
Available online 10 November 2021
1871-1413/

## 1. Introduction

Although cattle are well known for their high ability to digest fibre (Hoffmann, 1989), approximately 13% of the global cereal production is fed to ruminants, mainly cattle (Eisler et al., 2014; Mottet et al., 2017). At the same time, the prevalence of undernourishment amongst humans is 11% (FAOSTAT, 2020). Successful genetic selection for increased output (milk and meat) has led to the excessive use of human-edible foods in ruminant production systems, especially in developed countries (Bywater and Baldwin, 1980; Wilkinson and Lee, 2018). The reasons for using energy and protein concentrates, often consisting of human edible products, in ruminant rations include meeting nutritional requirements, balancing nutrient supply, increasing nutrient use efficiency, improving animal health and reducing greenhouse gas emissions (Wilkinson and Lee, 2018). Livestock production should serve to increase overall human food production. Consequently, it might be appropriate to calculate animal efficiency in terms of inputs of human-edible foods, as compared to total feed inputs (Bywater and Baldwin, 1980; Wilkinson, 2011). Regarding the returns on human-edible inputs, ruminants are superior to monogastric animals (Bywater and Baldwin, 1980; Wilkinson, 2011) due to their impressive ability to digest fibre. Additionally, ruminant feeding systems with a reduced use of concentrates consisting of human-edible raw materials generally perform better in terms of returns on human-edible inputs (Ertl et al., 2015; Wilkinson and Lee, 2018).

Therefore, it is not surprising that there are efforts to investigate the effects of reduced concentrate use in dairy cow rations. The amount of concentrate supplementation (0 to 2400 kg concentrate per cow and year) and the corresponding reduction (360 to 2100 kg concentrate per cow and year) differ considerably between studies (Ertl et al., 2014; Leiber et al., 2017; Sehested et al., 2003; Spiekers et al., 2018). But according to the authors knowledge, only Rae et al. (1987) tested an all-herbage diet in dairy cows. A reduction in concentrate for dairy cows without the noticeable impairment of health and metabolic processes seems possible (Ertl et al., 2014; Leiber et al., 2017; Rae et al., 1987; Sehested et al., 2003; Spiekers et al., 2018). In addition, no large effects on fertility characteristics were detected (Ertl et al., 2014; Leiber et al., 2017; Rae et al., 1987; Sehested et al., 2003). In the majority of the above-mentioned publications, the effects of increased concentrate supplementation were similar to those described in the review of Bargo et al. (2003) for pasture-based feeding systems.

In many countries in Europe, the milk-emphasised Holstein-Friesian breed plays a dominant role in organic milk production (Krieger et al., 2017; Marley et al., 2010; Nauta et al., 2005), in contrast to Switzerland, where mainly Swiss Brown cattle and Fleckvieh are used (Haas and Bapst, 2004, Spengler Neff A. personal communication regarding the current state). Cultural differences and, certainly, also the strict long-standing regulations concerning the use of concentrate in organic milk production have led to these differences. Up to the end of 2021, the proportion of concentrates is limited to 10% of dry matter (DM) in the annual ration for ruminants and will be further reduced to 5% from 2022 onwards (BioSuisse, 2020). In addition, the Swiss Federal Office for Agriculture considered an all-herbage ration for cattle in a revision of a subsidised grassland-based cattle milk and meat production program for conventional and organic farms (Schori, 2020a). Allowing up to 40% concentrate on a daily basis and even 50% during the first 3 months of lactation, the European regulations (EU Regulation 2018/848) are significantly more liberal in relation to supplemented concentrate for cattle in organic farming.

In a large-scale study of Swiss low-input organic farms (Leiber et al., 2017), a lack of impact on milk composition, fertility and veterinary treatments was found in relation to the reduction of concentrate. Improvements in the management of the dairy cow herds may have contributed to the outcome of the study because the concentrate feed reduction took place over a period of years and the farmers were continuously advised of such. Moreover, no simultaneous control group was implemented on a per-farm basis, and the maximum amount of concentrates offered was modest, about 6% of the annual ration. For the safe implementation of a severe limitation or ban on concentrate supplements in dairy cows' diets beyond organic farming, further knowledge are required. Knowledge about the effects of contrasting treatments, specifically all-herbage versus additional concentrate, which should be simultaneously compared over an entire lactation period using different cow types, is needed. There are many publications (see above) investigating reduced concentrate use, but recently, no studies, to the authors knowledge, have investigated pure all-herbage rations for dairy cows. The objective of this study was to investigate the effects of an all-herbage ration, as compared to a herbage-based ration with concentrate supplementation of 750 kg per cow on milk yield and composition, somatic cell count (SCC), body condition score (BCS), body weight (BW), medical treatments and reproduction issues in two Holstein cow types.

## 2. Animals, material and methods

All experimental procedures were performed in accordance with the Swiss Animal Welfare Act and approved by the Office of Food Safety and Veterinary of the Canton of Fribourg (2014–51-FR, 2015–60-FR and 2016–49-FR).

### 2.1. Animals

This three-year study started in January 2015 and was carried out at the 'Ferme Ecole de Sorens' organic farm in Sorens, Switzerland (latitude 46.663, longitude 7.052, 824 m a.s.l., mountain zone 1). Over the 3 years, the lactating herd included, on average, 75 dairy cows. Experimental and remaining cows were kept as one herd. In total, the experimental animals consisted of 92 Holstein cows, 67 of Swiss origin (HCH) and 25 of New Zealand origin (HNZ). Cows, after having performed a standard lactation in the experiment, were used several years, if they have calved again within the desired time window suited as a partner for pair formation and finally completed a standard lactation again. Because the HCH cows had been reared on the farm and the pasture-based, low-input feeding system that had been in place since 2004, it might be assumed that they were adapted to the system. The HNZ herd originated from pregnant heifers imported in 2006 from Ireland, with a genetic origin of predominantly New Zealand Holstein-Friesian (Schori and Münger, 2014). These imported animals and their offspring were bred to New Zealand Holstein Friesians bulls. Holstein Switzerland (Posieux, CH) estimated a total breeding index (ISET, population average = 1000) for 59 of the 67 HCH and 22 of the 25 HNZ. The ISET consists of indexes for production (IPL), conformation (ITP) and functional traits (IFF). In all sub-indexes, the population average is set to 100. The HCH exhibited an ISET of 935 ± 57 (SD), an IPL of 94 ± 7, an ITP of 99 ± 6 and an IFF of 97 ± 6. Compared to the HCH, the HNZ revealed similar ISET (928 ± 30) and IPL (93 ± 6) values. However, their ITP (53 ± 15) values were clearly lower, and their IFF (117 ± 7) values were markedly higher.

### 2.2. Production system

A herbage-based feeding system was in place for the dairy cows. Most calvings took place during the first four months of the year. The grazing season for the dairy cows started at the end of March (2015: 25th, 2016: 31st, 2017: 15th) and lasted until November (2015: 19th, 2016: 4th, 2017: 4th). Between two grazing seasons, around 145 d, the cows were kept in cubicle housing with outdoor access to a solid concrete floor. During the grazing season, pasture was the only forage, with a transient hay supplement offered until mid-May and from October onwards. Throughout the non-grazing period, hay was the only forage. Table 1 contains the average chemical composition and nutritive value data for hay and grazed herbage. For adaptation purposes and because of insufficient pasture availability, the dairy cows were grazed only for

**Table 1**
Average chemical composition and estimated nutritive value of grazed herbage, hay and concentrates.

| | Herbage $n = 45$ Mean | SD | Hay $n = 24$ Mean | SD | Energy[a] $n = 16$ Mean | SD | Protein[b] $n = 12$ Mean | SD |
|---|---|---|---|---|---|---|---|---|
| Analysed nutrients g kg$^{-1}$ DM | | | | | | | | |
| Organic matter | 885 | 24.9 | 901 | 15.7 | 936 | 11.5 | 911 | 5.7 |
| Crude protein | 178 | 38.4 | 104 | 12.3 | 130 | 11.2 | 420 | 15.3 |
| Ether extract | | | | | 47 | 6.8 | 95 | 16.7 |
| ADF[c] | 235 | 37.0 | 302 | 23.0 | 71 | 13.3 | 93 | 10.2 |
| NDF[d] | 434 | 55.2 | 534 | 30.3 | 205 | 35.8 | 188 | 58.4 |
| Energy value MJ kg$^{-1}$ DM | | | | | | | | |
| NEL[e] | 6.1 | 0.41 | 5.1 | 0.29 | 8.0 | 0.11 | 8.4 | 0.22 |

[a] energy-rich concentrate.
[b] protein-rich concentrate.
[c] acid detergent fibre.
[d] neutral detergent fibre.
[e] net energy for lactation.

half-days at the beginning and the end of the grazing season. In between these half-day periods, the cows had access to the pasture between 16 and 20 h daily, interrupted only by two milking sessions (5.00–7.00 h and 16.00–18.00 h). The herd was grazed in a rotational system with a maximum of 19 paddocks. Almost the entire pasture area was long established and composed mainly of grass-dominated (> 70% grasses) or balanced (50 to 70% grasses) plant communities (Agroscope 2020). Ryegrass was not predominant. The pre- and post-grazing sward surface heights were measured regularly with a C-Dax Pasture meter (C-DAX Ltd. Palmerston, North, NZ). Over the three grazing seasons, the average pre-grazing sward surface height ($n = 266$) was 107 ± 21 (SD) mm, which corresponds to an estimated herbage mass of 779 ± 279 (SD) kg DM ha$^{-1}$ above 48 mm (Schori, 2020b). The average post-grazing sward surface height was 53 ± 5 (SD) mm.

The daily average ambient outdoor temperature during the three years was 9 °C (minimum -12 °C, maximum 27 °C), and the precipitation amounted to between 1002 and 1447 mm per year (MeteoSchweiz, Station Marsens, Switzerland, 1.5 km east of the farm).

### 2.3. Concentrate supplementation treatments and allocation

Concurrently, two concentrate supplementation treatments were investigated. The first treatment was an all-herbage ration (AH) without concentrate supplementation for the entire lactation period, and the second consisted of 750 kg concentrate (C750), which were distributed during the first 300 days of lactation. In the C750 treatment, with an adaptation period from day 0 to 21 of lactation, the cows were offered 4.5 kg (as offered) during the first 100 days in milk (DIM), 2.5 kg until the 200th DIM and, finally, 1 kg of concentrate per day until the 300th DIM. The concentrates were distributed using three automatic feed stations in the barn (Delaval AG, Sursee, CH). During the grazing season, the cows exclusively received an energy-rich concentrate (first and second year No. 275, UFA AG, Herzogenbuchsee, CH; third year No. 8311, Mühle Rytz AG, Biberen, CH) whereas the winter ration supplement was made up of energy- and protein-rich concentrates (first and second year No. 277 UFA AG.; third year No. 8381, Mühle Ritz AG). Depending on hay quality, the proportion of protein-rich concentrate varied between winter feeding periods from 1/5 to 1/3 of the total daily concentrate amount. The proportion was fixed based on ration calculations (FUPLAN, Agridea, Lindau, CH). In Table 1, the chemical composition and nutritive value of the commercial organic concentrates are presented. The amounts of concentrates dispensed are averaged by cow type in Table 2.

Every year, before the calving season started in December, matched pairs were built within healthy HCH and HNZ according to number of lactations and expected calving date. In the first year, the HCH and HNZ pairs were randomly allocated to the AH and C750 treatments. Cows from the first experimental year were assigned to the other concentrate treatment in the second year. In the third year, the treatments were not switched again. Each year, new animals were introduced into the experiment.

**Table 2**
Average and standard deviation of the dispensed amounts (as offered) of concentrates per lactation.

| | All-herbage ration | | C750[a] | |
|---|---|---|---|---|
| | HCH[b] | HNZ[c] | HCH[b] | HNZ[c] |
| Number of lactations | 49 | 20 | 49 | 20 |
| Energy-rich concentrate (kg) | 0.3 | 0.6 | 646 | 670 |
| Standard deviation | 1.6 | 2.5 | 39 | 36 |
| Protein-rich concentrate (kg) | 0.1 | 0.7 | 99 | 81 |
| Standard deviation | 0.4 | 2.9 | 36 | 37 |
| Total of concentrate (kg) | 0.4 | 1.2 | 745 | 751 |
| Standard deviation | 1.6 | 3.7 | 21 | 22 |

[a] 750 kg concentrate.
[b] Holstein cows of Swiss origin.
[c] Holstein cows of New Zealand origin.

### 2.4. Sample collection and data recording

During the grazing season, two representative herbage strips with a length of approximately 7.5 m each were cut every 14 days on the paddocks next to be grazed. For the assessment of herbage quality, a pooled sample of the two strips was dried and analysed using wet chemistry. During transitional feeding – winter/summer and vice versa – and winter feeding, the offered hay was sampled once per week. These weekly samples were combined into one pooled sample per month. The energy-rich concentrate was sampled every 3 months throughout the years. During the winter feeding periods the protein-rich concentrate was sampled every 2 months. Hay and concentrate samples were analysed by wet chemistry.

Every 14 days, the daily milk yield (sum of the morning and evening milking) of each cow was recorded (Flowmaster Pro, Delaval AG), and milk samples from two consecutive milkings (morning and evening milking) were taken by breeding association personnel (Holstein Switzerland). The milk samples were used to analyse fat, protein, lactose and urea via infrared spectrometry, and SCC were analysed via an optical fluorescent technique. The BCS of the lactating cows was evaluated monthly on a scale from 1 to 5 (Edmonson et al., 1989). After each milking, the dairy cows were weighed in an automatic weighing system (Delaval AG). The farm employees recorded the medical treatments in the herd management program (ALPRO, Delaval AG).

### 2.5. Calculations and statistical analysis

The experimental unit is the standard lactation of a cow. Based on the fortnightly milk yield recordings and milk samples analysis (at least 19 for standard lactations lengths of 270 d and at most 22 for 305 d), the yields and averaged milk contents were summarised to a value for the standard lactation according to the test interval method (ICAR, 2020). Body weight (two daily records were averaged for two weeks and subsequently for the standard lactation) and BCS (9 to 10 records, as they were estimated monthly) were averaged over the length of the standard lactation. The energy-corrected milk yield (ECM) was computed as proposed in Jans et al. (2017). For the statistical analysis, R (R Core Team, 2019) was used. The milk yields, milk constituents, SCC (log transformed), BW, BCS and milk yields per BW of the standard lactation were analysed using linear mixed models (packages "lmerTest", Kuznetsova et al., 2017). As fixed factors, the concentrate treatments (AH, C750), cow types (HCH, HNZ) and their interaction were used. The individual cows were considered as random effect.

The medical treatments were clustered into six groups of health issues: (1) fertility (treatments related to anoestrus, ovarian cysts, retained placenta and the uterus), (2) feeding (administration of trace mineral boluses, propylene glycol or a bolus containing salts of propionic acid, minerals, vitamins and herbs), (3) claws and legs (antibiotic suspensions injections or special hoof care due to lameness), (4) mastitis (intramammary application of antibiotics), (5) milk fever (Calcium infusions, preventive application of dietary mineral product or vitamin D3 injections) and (6) various (antibiotic suspension injections, administration of analgesics or oxytocin injection). Multiple treatments of cows for the same disorder within the same lactation were considered individually. For the analysis of health issue data as well as the number of lactations without a subsequent calving, the concentrate treatment and cow type factors were considered using the Chi-square test. First service interval, service period, calving interval and services per conception of re-calving cows were analysed using the Kruskal-Wallis-Test.

## 3. Results

In total, 138 lactation records (46, 54 and 38 lactations in the 1st, 2nd and 3rd year, respectively) from 92 cows were examined over the three years. Forty lactation records of 25 HNZ and 98 lactation records of 67 HCH cows were taken into account for the evaluation. In both concentrate treatments the average lactation number of the cows was 2.1. The average lactation numbers for HCH and HNZ were 2.0 and 2.4, respectively. In total, 92% of calvings took place between late December and late April.

In C750, dairy cows produced per standard lactation more milk, ECM, milk fat, milk protein, lactose, ECM per BW, and ECM per unit of metabolic body size (Table 3). In addition, concentrate-supplemented cows showed slightly higher BW and BCS values (Table 3, Fig. 1). The milk content of fat, protein, lactose and urea, as well as SCC, remained unchanged by concentrate supplementation. The HCH produced more milk and lactose per standard lactation. Due to the lower fat, protein and lactose content in the milk of HCH, no significant differences were found concerning ECM, milk fat and milk protein yield per standard lactation between the two cow types. As the HCH were heavier and did not significantly yield more ECM, they produced less ECM per BW or unit of metabolic body size than HNZ. Furthermore, HCH were assigned, on average, lower BCS ratings than HNZ. Finally, the two cow types, HCH and HNZ, showed similar values regarding milk urea content and SCC. None of these traits approached the significance level ($P < 0.05$) regarding the interaction between the concentrate supplementation and cow type factors. Details can be found in Table 3.

The medical treatments listed in Table 4 were only considered for

**Table 3**
Least square means and standard errors for milk production, milk content, somatic cell counts, BW and BCS (summed or averaged per standard lactation).

| | All-herbage ration | | C750[a] | | *P*-values | | |
|---|---|---|---|---|---|---|---|
| | HCH[b] | HNZ[c] | HCH[b] | HNZ[c] | Concentrate | Cow type | Interaction |
| Number of lactations | 49 | 20 | 49 | 20 | | | |
| Standard lactation milk yield (kg) | 5577 | 4905 | 6454 | 5622 | < 0.001 | < 0.001 | 0.54 |
| Standard Error | 137 | 207 | 135 | 203 | | | |
| Standard lactation ECM[d] yield (kg) | 5514 | 5239 | 6371 | 6053 | < 0.001 | 0.13 | 0.88 |
| Standard Error | 130 | 198 | 129 | 194 | | | |
| Milk fat (kg) | 228 | 222 | 262 | 250 | < 0.001 | 0.33 | 0.60 |
| Standard Error | 6 | 9 | 6 | 9 | | | |
| Milk fat (%) | 4.09 | 4.55 | 4.07 | 4.46 | 0.31 | < 0.001 | 0.47 |
| Standard Error | 0.05 | 0.08 | 0.05 | 0.08 | | | |
| Milk protein (kg) | 178 | 172 | 207 | 201 | < 0.001 | 0.32 | 0.96 |
| Standard Error | 4 | 7 | 4 | 6 | | | |
| Milk protein (%) | 3.19 | 3.52 | 3.22 | 3.58 | 0.15 | < 0.001 | 0.60 |
| Standard Error | 0.03 | 0.04 | 0.03 | 0.04 | | | |
| Lactose (kg) | 259 | 231 | 300 | 264 | < 0.001 | 0.001 | 0.53 |
| Standard Error | 6 | 9 | 6 | 9 | | | |
| Lactose (%) | 4.64 | 4.70 | 4.66 | 4.72 | 0.27 | 0.06 | 0.77 |
| Standard Error | 0.02 | 0.02 | 0.02 | 0.03 | | | |
| Milk urea (mg $dl^{-1}$) | 23.9 | 24.0 | 24.0 | 22.9 | 0.41 | 0.52 | 0.28 |
| Standard Error | 0.5 | 0.8 | 0.5 | 0.8 | | | |
| SCC[e] (log10 $ml^{-1}$) | 4.95 | 4.95 | 4.93 | 5.04 | 0.52 | 0.46 | 0.28 |
| Standard Error | 0.05 | 0.07 | 0.05 | 0.07 | | | |
| Body weight (kg) | 595 | 524 | 607 | 539 | 0.048 | < 0.001 | 0.84 |
| Standard Error | 9 | 14 | 9 | 14 | | | |
| BCS | 2.51 | 2.80 | 2.62 | 2.87 | 0.03 | < 0.001 | 0.64 |
| Standard Error | 0.04 | 0.06 | 0.04 | 0.06 | | | |
| ECM[d] per body weight (kg $kg^{-1}$) | 9.30 | 10.07 | 10.50 | 11.22 | < 0.001 | 0.002 | 0.90 |
| Standard Error | 0.17 | 0.25 | 0.17 | 0.25 | | | |
| ECM per $BW^{0.75}$ (kg $kg^{-1}$)[f] | 45.9 | 48.1 | 52.1 | 54.0 | < 0.001 | 0.08 | 0.89 |
| Standard Error | 0.8 | 1.3 | 0.8 | 1.2 | | | |

[a] 750 kg concentrate.
[b] Holstein cows of Swiss origin.
[c] Holstein cows of New Zealand origin.
[d] energy corrected milk yield.
[e] somatic cell counts.
[f] energy corrected milk yield per unit metabolic body size.

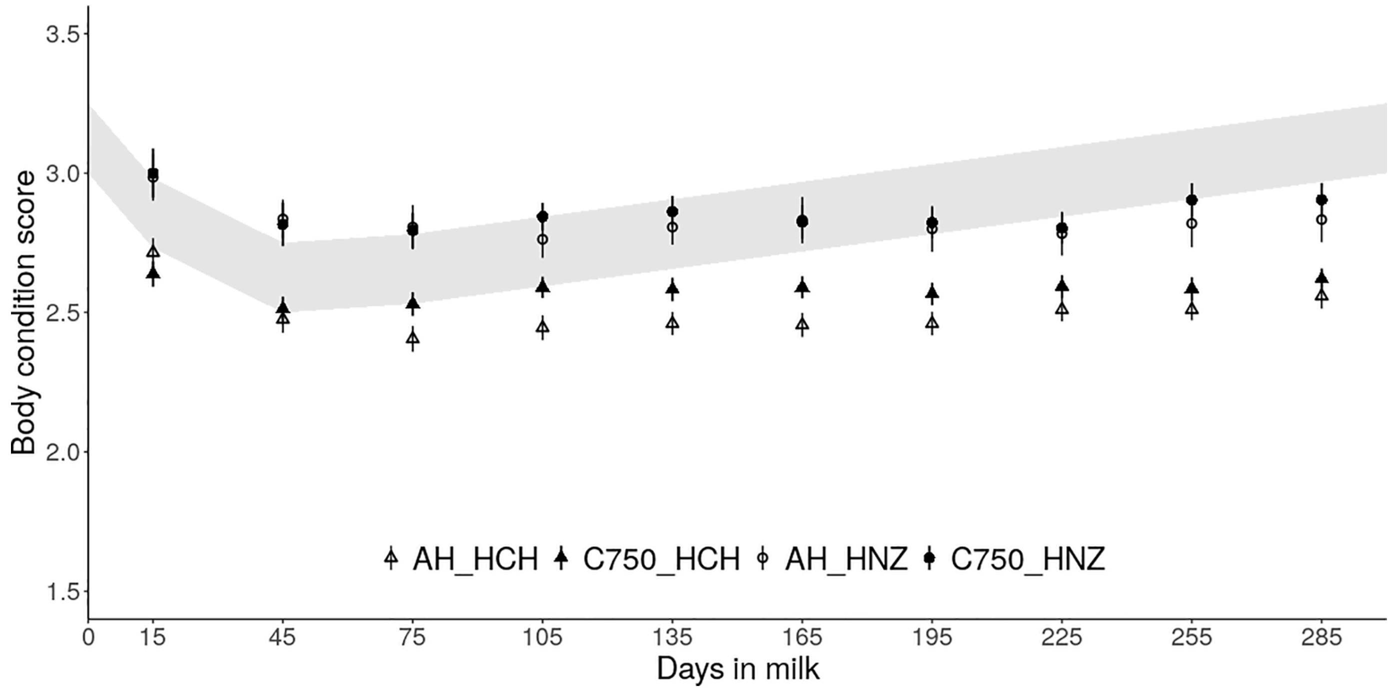


**Fig. 1.** Mean (± standard error) body condition scores during standard lactations for Holstein cows of Swiss (HCH) and New Zealand (HNZ) origin in the all-herbage (AH) and 750 kg concentrate (C750) treatments. The grey ribbon corresponds to the body condition score recommendations of Roche et al. (2009).

**Table 4**
Number of medical treatments grouped in six health issues.

| | All-herbage ration | | C750[a] | | *P*-values | |
|---|---|---|---|---|---|---|
| | HCH[b] | HNZ[c] | HCH[b] | HNZ[c] | Conc.[d] | Cow type |
| Number of lactations | 49 | 20 | 49 | 20 | | |
| Fertility | 75 | 14 | 61 | 14 | 0.27 | < 0.001 |
| Feeding | 4 | 2 | 1 | 0 | -[e] | -[e] |
| Claws and legs | 3 | 5 | 5 | 7 | 0.37 | 0.002 |
| Mastitis | 14 | 2 | 11 | 5 | 1.00 | 0.38 |
| Milk fever and prevention | 4 | 1 | 5 | 1 | 0.76 | -[e] |
| Various | 7 | 2 | 8 | 2 | 0.82 | -[e] |
| Total | 107 | 26 | 91 | 29 | 0.41 | 0.01 |

[a] 750 kg concentrate.
[b] Holstein cows of Swiss origin.
[c] Holstein cows of New Zealand origin.
[d] Concentrate.
[e] CHI-square test becomes inaccurate for frequencies < 5, so in these cases, the *P*-values were omitted.

cows with completed standard lactations. Over the three years, a total of 101 and 95 dairy cows were allotted, before calving, into AH and C750, respectively (pairs and reserve cows). Of these, twelve and eight cows in AH and C750, respectively, did not finish the standard lactation ($P = 0.45$). The reasons for removal of cows were, in decreasing order, severe or chronic udder infections, injuries or accidents and bloat. As set out in Table 4, the concentrate treatments, AH and C750, did not differ regarding the number of medical treatments. In contrast, differences in this regard appeared between the two cow types. The HCH received more treatments for reproduction issues and in total than HNZ. On the other hand, fewer treatments were necessary for claw and leg issues for HCH than for HNZ.

Reproductive traits are shown in Table 5. The AH treatment tended to produce more lactations without a subsequent calving. No significant differences concerning the reproduction traits were found between the two feeding treatments. In contrast, the calving intervals of the HCH were significantly longer, and the interval between calving and first service, as well conception, tended to be longer. Regarding services per calving, there was no difference between cow types.

## 4. Discussion

### *4.1. Effect of the concentrate levels on production traits*

In contrast to maize, herbage, especially in its fresh form, would be suitable as a complete feed for dairy cows (Delaby et al., 2003). With an all-herbage ration, consisting solely of grazed herbage and hay, the cows produced a respectable yield of 5376 kg ECM (3480 to 8162 kg) per standard lactation. Even though the hay was of modest quality, with 5.1 MJ net energy for lactation and 104 g crude protein , this output was possible. Furthermore, it must be mentioned that the pasture paddocks were between 800 and 900 m a. s. l. and that the meadows used for hay making were predominantly between 900 and 1000 m a. s. l. In the early 1980s, using also a true all-herbage ration, Rae et al. (1987) obtained milk yields over the complete lactation of 4006 kg for primiparous and 4680 kg for multiparous Holstein-Friesian cows under more favourable conditions. There are no recent publications, to our knowledge, that report standard lactation milk yields for dairy cows on all-herbage rations. Sehested et al. (2003) offered the cows in the «zero concentrate» treatment 126 kg DM concentrate, 207 kg DM fodder beets per cow and year on top of a clover-grass based forage ration; Danish Holstein and Red Dairy Breed cows produced 5090 kg ECM per year with this ration. With a concentrate supplementation of approximately 370 kg per cow and year to a grass ration, Horan et al. (2005) attained, with a mix of Holstein-Friesian strains, 6025 and 6200 kg solid-corrected milk yields per complete lactation. If an all-forage ration contains high-quality maize silage and preserved herbage, average herd productions of 8100 kg per cow and year are possible (Brandenburger et al., 2008).

In treatment C750, the cows produced per standard lactation 775 kg ECM more than in AH, which equates to an ECM response of 1.04 kg/kg of additional concentrate (as fed). In a review, Bargo et al. (2003) report an overall linear milk response of 1 kg milk/kg DM concentrate in a range of 1.2 to 10 kg DM of concentrate distributed daily per cow.

**Table 5**
Reproductive traits.

| | All-herbage ration | | C750[a] | | N[b] | Min/max | P-values | |
|---|---|---|---|---|---|---|---|---|
| | HCH[c] | HNZ[d] | HCH[c] | HNZ[d] | | | Conc.[e] | Cow type |
| Number of lactations | 49 | 20 | 49 | 20 | 138 | | | |
| [f]Number of lactations without a subsequent calving | 17 | 3 | 9 | 1 | 30 | | 0.07 | –[h] |
| [g]Calving to first service (day, median) | 75 | 76 | 74 | 60 | 136 | 14 - 285 | 0.73 | 0.09 |
| [g]Calving to conception (day, median) | 91 | 89 | 105 | 80 | 108 | 40 - 285 | 0.60 | 0.07 |
| [g]Calving interval (day, median) | 374 | 365 | 386 | 355 | 108 | 319 - 563 | 0.63 | 0.03 |
| [g]Services per calvings (mean) | 1.9 | 1.9 | 2.3 | 2.0 | 108 | 1 – 8 | 0.15 | 0.64 |

[a]750 kg concentrate.
[b] Total number of lactations.
[c]Holstein cows of Swiss origin.
[d]Holstein cows of New Zealand origin.
[e]Concentrate.
[f]Evaluated with CHI-square test.
[g]Evaluated with Kruskal-Wallis Test.
[h]CHI-Square Test was performed and becomes inaccurate for frequencies < 5, so in these cases, the *P*-values were omitted.

Delaby et al. (2003) obtained similar milk responses, with an average of 0.94 ± 0.4 (SD) kg milk/kg DM of concentrate. Even in more recent studies (Horan et al., 2005; Heublein et al., 2017; Leiber et al., 2017), the milk yield responses are predominantly contained within the range from 0.6 to 1.45 kg milk/kg concentrate, as indicated by Bargo et al. (2003). Differences in the substitution rate may explain part of the variation in milk response to concentrates (Bargo et al., 2003; Delaby et al., 2003), but energy allocation between milk production and BW gain may play a role as well (Delaby et al., 2003). In turn, the substitution rate is affected by factors related to the availability and quality of pasture herbage, forage, supplements and animals (Bargo et al., 2003).

Increasing the amount of concentrate to 10 kg DM/d increased milk protein content by 4% as compared to pasture-only diets, but it reduced milk fat content by 6% (Bargo et al., 2003). Delaby et al. (2003) specified the content changes per kg DM of additional concentrate as −0.25 (± 0.55 SD) g fat/kg milk and +0.21 g protein/kg milk. It is not surprising that, in view of such marginal effects, no differences in milk fat and protein content were found between the treatments in our study. Depending on the ration, concentrate levels and distribution scheme, divergent findings are stated in relation to changes in milk fat and protein content (Horan et al., 2005; Heublein et al., 2017; Spiekers et al., 2018). Larger amounts of fat, protein and lactose were produced in C750 than AH because the cows in the former treatment gave more milk and had similar milk content. Similar to the results of Heublein et al. (2017), the lactose content remained unchanged in relation to concentrate distribution in our study. In contrast, Horan et al. (2005) noted higher lactose concentrations with increased concentrate supplementation. Likewise, in some experiments of the German collaborative project, higher energy concentrations of the base ration led to higher lactose content (Spiekers et al., 2018). Depending on the protein content of the base ration and the energy-enhanced concentrates used, the milk urea content will increase, decrease or stay the same. As we used, during the winter feeding period, partly protein concentrate, and, during the grazing season, solely energy-rich concentrates, the average milk urea content did not differ between the AH and C750 treatments. In Heublein et al. (2017), the milk and blood urea content decreased because only energy-rich concentrate was offered with the pasture-only diet. Additionally, the daily supplemented amounts were higher than in our study. With a large amount of concentrate, Bargo et al. (2003) recorded lower ruminal ammonia nitrogen concentration, which may be considered as a precursory indicator of milk urea content.

The SCC is used as an indicator of udder health. As in Sehested et al. (2003) and Leiber et al. (2017, somatic cell score), SCC did not differ between the treatments in our study. Ertl et al. (2014) noted a trend toward higher SCC without concentrate supplementation. It remains an open question, when comparing different farms' results, whether other factors may have influenced the outcome.

In our study, the effects of concentrate supplementation on BW (+ 14 kg) and BCS (+ 0.09) were, on average, smaller than commonly assumed, but they were still statistically significant. Delaby et al. (2003) report a mean increase of 60 (± 60 SD) g BW per day per kg DM of concentrate in their review. According to these data, there should have been a difference of 36 kg BW between the C750 and AH treatments. In Horan et al. (2005), the cows exhibited a 22 kg heavier BW at drying off with approximatively 950 kg DM more concentrate, which corresponds to roughly the BW difference observed in our study. In turn, the differences concerning BCS at drying off were more evident as compared to our study.

Finally, concentrate-supplemented dairy cows appear to be more efficient when comparing ECM per BW or unit of metabolic body size. Although concentrate substitutes for forage, total DM intake still increases, which may be responsible for the higher efficiency per BW or unit of metabolic body size.

### 4.2. *Production traits and holstein cow types*

As in other studies (Piccand et al., 2013; Schori and Münger, 2014; Heublein et al., 2017), HCH cows produced more milk than HNZ because they are larger. The differences between cow types concerning ECM are smaller and sometimes, as in our study, statistically insignificant (Piccand et al., 2013; Heublein et al., 2017). The substantially lower fat and protein content in the milk of HCH as compared to HNZ leads to this result. In our study, the HCH produced less ECM per unit of body weight, which is not supported by previous studies (Piccand et al., 2013; Schori and Münger, 2014; Thanner et al., 2014). Interestingly and in contrast to Thanner et al. (2014) and Heublein et al. (2017), the lactose content between the studied Holstein cow strains tended to be different. The causes of these different lactose content levels can only be speculated on. In fact, lactose content levels are relatively constant as the milk and lactose yields are closely related ($r = 0.99$, Costa et al. (2019)). Dillon et al. (2003) and Piccand et al. (2013) report breed differences in this regard, but not within Holstein cow strains. Horan et al. (2005) also found no strain effect regarding lactose content between Holstein cows. Lactose content is related to energy balance (Reist et al., 2002), udder health, metabolic disorders (Costa et al., 2019) and fertility traits (Buckley et al., 2003). In our study, different numbers of fertility treatments and differences in calving intervals were found between cow strains. No differences between Holstein cow strains are confirmed regarding milk urea content when offered identical rations (Thanner et al., 2014; Heublein et al., 2017) or regarding somatic cell counts (Piccand et al., 2013). Overall, the HCH are heavier, but they are also characterised by smaller BCS values than HNZ (Piccand et al., 2013; Schori and Münger, 2014; Thanner et al., 2014). With an average BCS of 2.51 (AH) and 2.62 (C750) during the standard lactation, the HCH were too lean. These BCS profiles, in contrast to those of HNZ, are outside the acceptable range suggested by Roche et al. (2009) to allow for milk production near genetic potential without compromising reproduction, health and animal welfare.

Apparently, the differences between Holstein cow strains and feeding treatments (AH and C750) were too small in our study, in contrast to Horan et al. (2005), so no feeding treatment x genotype interactions occurred.

### 4.3. Medical and fertility treatments

Although the experiment was comprehensive, the number of lactations included in our study is limited for consolidated statements on health and fertility. At fixed significance level and constant degrees of freedom the statistical power of the chi-squared test is determined by the effect size and the total number of observations. Consequently, the power of the chi-squared test varied post-hoc between 0.1 (milk fever and prevention) and near 1 (total medical treatments). For the Kruskal-Wallis test, which was used for the fertility traits, the effect size plays even a greater role, as the numbers of observations varied less. The post-hoc approximations for fertility traits resulted in a power between 0.1 and 0.7. Nevertheless, the evaluation of the number of medical treatments provides interesting insights for larger effect size. Furthermore, the recorded preventive treatments were also taken into account for the purpose of completeness. The two groups of health issues, feeding and milk fever were concerned. Compared to the number of fertility treatments and the total number of medical treatments the number of preventive treatments was low. With an average of 1.83 treatments per lactation, of which 2/3 (1.19) were for fertility issues, a very large number of treatments were carried out.

Various factors presumably led to this high number of medical treatments in our study. On the one hand, fertility plays a particularly important role in a low-input, pasture-based feeding system with accumulated calvings before the vegetation period starts (Shalloo et al., 2014). Furthermore, the farm takes part in a herd fertility and health programme offered by a nearby University of Veterinary Medicine, which may have resulted in increased medical treatments. Finally, some Holstein cow strains one-sidedly bred for milk production are known to have poorer reproductive characteristics (Pryce et al., 2014; Holstein Switzerland, 2020).

Rae et al. (1987) succinctly summarised the situation, in their experiment concerning animal health and fertility, regarding true all-herbage diets for late winter calving dairy cows as satisfactory. Other studies also report only small differences, if any, in health and fertility with reduced concentrate rations. For example, five years of modest concentrate reduction in low-input organic farms affected neither fertility nor veterinary treatments (Leiber et al., 2017). Even in some cases, significantly lower clinical treatment frequencies (Sehested et al., 2003) or lower veterinary costs (Ertl et al., 2014) were found when concentrate supplementation was strongly reduced. With decreasing concentrate supplementation, Sehested et al. (2003) observed a tendency toward an increasing number of days to first insemination, but without a difference in calving interval. In contrast to this study, Ertl et al. (2014) found longer calving intervals, but no differences in insemination index or non-return rate with decreasing concentrate levels. Furthermore, in a German collaborative project (Spiekers et al., 2018), it was concluded that different – but both considerable – amounts of concentrate (150 g or 250 g per litre of milk) are possible with all-year-round barn feeding, without any noticeable impairment of health and metabolism in the long term. Finally and more comparable to our study, Horan et al. (2004) detected no significant differential effect on reproduction performance between diverse supplemented pasture-based feeding systems.

Therefore, it is not surprising that, in our study, no significant differences in medical treatments and reproduction traits were found between the two feeding treatments, except for a tendency toward fewer calvings after the standard lactation in AH. Less re-calving is actually an important reproduction issue in dairy farming because it affects the replacement rate and, consequently, the profitability of milk production (Shalloo et al., 2014). The fact that nutrition affects reproduction in dairy cows has been shown in many ways (Bisinotto et al., 2012; Berry et al., 2016), but the extent of the effect is often largely exaggerated, according to Berry et al. (2016). This is at least partly supported by our study and the cited studies of reduced concentrate supplementation. Furthermore, the magnitude of the reduction is relevant. In our study, the difference in concentrate supplementation is more than twice as large as that investigated by Leiber et al. (2017). Nevertheless, the roughly estimated share of concentrate to annual DM intake may be only about 12%. Concerning reproductive failures, cow type or strain may be more important than nutrition (Berry et al., 2016). In fact, one-sided breeding for milk production, without considering fertility traits, has led to less fertile cows (Pryce et al., 2014; Berry et al., 2016). Although the pasture-based feeding system was introduced 12 years before our experiment started at the experimental farm and the HCH exhibited a production index below the average of the Swiss Holstein population, differences in fertility traits still seem to occur. An increased number of fertility treatments, tendencies toward increased calving-to-first-service and -conception intervals, as well as longer calving intervals for HCH than HNZ support this statement. The meta-analysis of Bedere et al. (2018) points out that the postpartum cyclicity of dairy cows was mainly associated with BCS at calving. In contrast, oestrus expression was mainly associated with milk yield, and fertility was associated with both BCS and milk yield. The HCH revealed lower BCS and higher milk yields per animal as compared to HNZ. Several studies identified the superiority, in relation to reproduction, of New Zealand Holstein cows as compared to North American Holstein cows (Kolver et al., 2002; Horan et al., 2004; Pryce et al., 2014) and Swiss Holstein cows (Pryce et al., 2014; Piccand et al., 2013). The results of Horan et al. (2004) and our results suggest that offering higher levels of concentrates may not alleviate the reduced reproduction performance of Holstein cows one-sidedly selected for milk production. According to Bedere et al. (2018) the improvement of reproductive performance in dairy cows may be achieved by appropriate BCS at calving, limited BCS losses postpartum and reduced peaks in milk yield. Breeding for milk and fertility is possible, although these traits are negatively correlated (Berry et al., 2016). Consequently, breeding for fertility does not necessarily require a reduction in milk production.

## 5. Conclusions

The omission of concentrate results in reduced yields, as expected. For dairy cows, milk yield is reduced by approximately 1 kg per 1 kg of omitted concentrate. The milk content, fat, protein, and lactose do not seem to be affected by leaving out the concentrates. Although BCS and body weight are significantly influenced, the extent seems to be moderate, as is the case for the number of medical treatments. These differences seem to be much greater between the cow types. All-herbage rations remain feasible today, but dairy cows adapted to cope with adversities commonly associated with low-input feeding systems might be advantageous to use considering BCS, medical treatments and fertility traits.

## CRediT authorship contribution statement

**F. Schori:** Conceptualization, Methodology, Investigation, Formal analysis, Project administration, Writing – original draft. **A. Münger:** Conceptualization, Methodology, Writing – review & editing.

## Acknowledgement

Thanks are due to the staff of the 'Ferme Ecole de Sorens' organic farm and the Agroscope staff for carrying out the experiment.

## References


Bargo, F., Muller, L.D., Kolver, E.S., Delahoy, J.E., 2003. Invited review: production and digestion of supplemented dairy cows on pasture. J. Dairy Sci. 86, 1–42 https://doi.org/10.3168/jds.S0022-0302(03)73581-4.

Bedere, N., Cutullic, E., Delaby, L., Garcia-Launay, F., Disenhaus, C., 2018. Meta-analysis of the relationships between reproduction, milk yield, and body condition score in dairy cows. Livst. Sci. 210, 73–84 https://doi.org/10.1016/j.livsci.2018.01.017.

Berry, D.P., Friggens, N.C., Lucy, M., Roche, J.R., 2016. Milk production and fertility in cattle. Annu. Rev. Anim. Biosci. 4, 260–290 https://doi.org/10.1146/annurev-animal-021815-111406.

BioSuisse, 2020. Richtlinien Für Die Erzeugung, Verarbeitung und Den Handel von Knospen-Produkten. BioSuisse, Basel. https://www.bio-suisse.ch/de/richtlinienweisungen.php. accessed 29 May 2020.

Bisinotto, R.S., Greco, L.F., Ribeiro, E.S., Martinez, N., Lima, F.S., Staples, C.R., Thatcher, W.W., Santos, J.E.P., 2012. Influences of nutrition and metabolism on fertility of dairy cows. Anim. Repro. 9, 260–272.

Brandenburger, C., Von Ah, E., Latscha, A., 2008. Herdentrennung am LBBZ Plantahof Erfahrungen und Resultate aus dem Praxisversuch von 2003–2007, in Rahmann, G., Schumacher, U., (Eds.) Neues Aus Der Ökologischen Tierhaltung 2008. vTI, Braunschweig, Germany. pp. 119–130.

Buckley, F., O'Sullivan, K., Mee, J.F., Evans, R.D., Dillon, P., 2003. Relationships among milk yield, body condition, cow weight, and reproduction in spring-calved Holstein-Friesians. J. Dairy Sci. 86, 2308–2319 https://doi.org/10.3168/jds.S0022-0302(03)73823-5.

Bywater, A.C., Baldwin, R.L., 1980. Alternative strategies in food-animal production. In: Baldwin, R. L. (Ed.), Animals, Feeds, Foods and People, Westview Press, Boulder, pp. 1–30.

Costa, A., Egger-Danner, C., Mészáros, G., Fuerst, C., Penasa, M., Sölkner, J., Fuerst-Waltl, B., 2019. Genetic associations of lactose and its ratios to other milk solids with health traits in Austrian Fleckvieh cows. J. Dairy Sci. 102, 4238–4248 https://doi.org/10.3168/jds.2018-15883.

Delaby, L., Peyraud, J.L., Delagarde, R., 2003. Faut-il complémenter les vaches laitières au pâturage? INRA Prod. Anim. 16 (3), 183–195 https://doi.org/10.20870/productions-animales.2003.16.3.3659.

Dillon, P., Buckley, F., O'Connor, P., Hegarty, D., Rath, M., 2003. A comparison of different dairy cow breeds on a seasonal grass-based system of milk production. 1. Milk production, live weight, body condition score and DM intake. Livest. Prod. Sci. 83, 21–33 https://doi:10.1016 /S0301-6226(03)00041-1.

Edmonson, A.J., Lean, I.J., Weaver, L.D., Farver, T., Webster, G., 1989. A body condition scoring chart for Holstein dairy cows. J. Dairy Sci. 72, 68–78 https://doi.org/10.3168/jds.S0022-0302(89)79081-0.

Eisler, M.C., Lee, M.R.F., Tarlton, J.F., Martin, G.B., Beddington, J., Dungait, J.A.J., Greathead, H., Liu, J., Mathew, S., Miller, H., Misselbrook, T., Murray, P., Vinod, V. K., Van Saun, R., Winter, M., 2014. Steps to sustainable livestock. Nature 507, 32–34 https://doi.org/10.1038/507032a.

Ertl, P., Klocker, H., Hörtenhuber, S., Knaus, W., Zollitsch, W., 2015. The net contribution of dairy production to human food supply: the case of Austrian dairy farms. Agric. Syst. 137, 119–125 https://doi.org/10.1016/j.agsy.2015.04.004.

Ertl, P., Knaus, W., Steinwidder, A., 2014. Comparison of zero concentrate supplementation with different quantities of concentrates in terms of production, animal health, and profitability of organic dairy farms in Austria. Org. Agr. 4, 233–242 https://doi.org/10.1007/s13165-014-0077-z.

EU Regulation 2018/848, 2018. Regulation On Organic Production and Labelling of Organic Products. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018R0848&from=DE. accessed 28. May 2020.

FAOSTAT, 2020. faohttp://faostat.fao.org/static/syb/syb_5000.pdf (accessed 27 May 2020).

Haas, E., Bapst, B., 2004. Swiss organic dairy farmer survey: which path for the organic cow in the future. In: Proceedings 2nd SAFO Workshop. Witzenhausen (Germany). https://orgprints.org/3168/1/haas-bapst-2004-swiss-organic-dairy-famer-survey.pdf. assessed 28. May 2020.

Heublein, C., Dohme-Meier, F., Südekum, K.-H., Bruckmaier, R.M., Thanner, S., Schori, F., 2017. Impact of cow strain and concentrate supplementation on grazing behaviour, milk yield and metabolic state of dairy cows in an organic pasture-based feeding system. Animal 11, 1163–1173 https://doi:10.1017/S1751731116002639.

Hoffmann, R.R., 1989. Evolutionary steps on ecophysiological adaptation and diversification of ruminants: a comparative view of their digestive system. Oecologia 78, 443–457 https://doi.org/10.1007/BF00378733.

Holstein Switzerland, 2020. Rapport de gestion, https://www.holstein.ch/wp-content/uploads/rapport_de_gestion2019_low.pdf (assessed 14. August 2020).

Horan, B., Dillon, P., Faverdin, P., Delaby, L., Buckley, F., Rath, M., 2005. The interaction of strain of Holstein-Friesian cows and pasture-based feed systems of milk yield, body weight, and body condition score. J. Dairy Sci. 88, 1231–1243 https://doi.org/10.3168/jds.S0022-0302(05)72790-9.

Horan, B., Mee, J.F., Rath, M., OConnor, P., Dillon, P., 2004. The effect of strain of Holstein-Friesian cow and feeding system on reproductive performance in seasonal-calving milk production systems. Anim. Sci. 79, 453–467 https://doi.org/10.1017/S1357729800090329.

ICAR, 2020. Computing of Accumulated Lactation Yield. In: https://www.icar.org/Guidelines/02-Procedure-2-Computing-Lactation-Yield.pdf. accessed, 30. January 2020.

Jans, F., Kessler, J., Münger, A., Schori, F., Schlegel, P., 2017. Fütterungsempfehlungen für die Milchkuh, Agroscope (Ed.), in Fütterungsempfehlungen Für Wiederkäuer. Agroscope, Posieux, https://www.agroscope.admin.ch/agroscope/de/home/services/dienste/futtermittel/fuetterungsempfehlungen_wiederkaeuer/_jcr_content/par/columncontrols_517414399/items/0/column/externalcontent.external.exturl.pdf/aHR0cHM6Ly9pcmEuYWdyb3Njb3BlLmNoLzAvQWpheC9FaW56ZW/xwdWJsaWthdGlvbi9Eb3dubG9hZD9laW56ZWxwdWJsaWthdGlv/bklkPTQxNTk1.pdf (assessed 30. January 2020).

Kolver, E.S., Roche, J.R., De Veth, M.J., Thorne, P.L., Napper, A.R., 2002. Total Mixed Rations Versus Pasture diets: Evidence for a Genotype x Diet Interaction in Dairy Cow Performance. In: http://www.nzsap.org/system/files/proceedings/2002/total-mixed-rations-versus-pasture-diets-evidence-genotype-x-diet-concentration-amino-acid-derived.pdf. assessed 27. August 2020.

Krieger, M., Sjöström, K., Blanco-Penedo, I., Madouasse, A., Duval, J.D., Bareille, N., Fourichon, C., Sundrum, A., Emanuelson, U., 2017. Prevalence of production disease related indicators in organic dairy herds in four European countries. Livest. Sci. 198, 104–108 http://dx.doi.org/10.1016/j.livsci.2017.02.015.

Kuznetsova, A., Brockhoff, P.B., Christensen, R.H.B., 2017. lmerTest Package: tests in linear mixed effects models. J. Stat. Softw. 82 (13), 1–26 https://doi: 10.18637/jss.v082.i13.

Leiber, F., Schenk, I.K., Maeschli, A., Ivemeyer, S., Zeitz, J.O., Moakes, S., Klocke, P., Staehli, P., Notz, C., Walkenhorst, M., 2017. Implications of feed concentrate reduction in organic grassland-based dairy systems: a long-term on-farm study. Animal 11, 2051–2060 https://doi.org/10.1017/S1751731117000830.

Marley, C.L., Weller, R.F., Neale, M., Main, D.C.J., Roderick, S., Keatinge, R., 2010. Aligning health and welfare principles and practice in organic dairy systems: a review. Animal 4, 259–271 https://doi.org/10.1017/S1751731109991066.

Mottet, A., de Haan, C., Falcucci, A., Tempio, G., Opio, C., Gerber, P., 2017. Livestock: on our plates or eating a tour table. A new analysis of the feed/food debate. Glob. Food Security 14, 1–8 https://doi.org/10.1016/j.gfs.2017.01.001.

Nauta, W.J., Groen, A.F., Veerkamp, R.F., Roep, D., Baars, T., 2005. Animal breeding in organic dairy farming: an inventory of farmers' views and difficulties to overcome. NJAS-Wagen. J. Life Sci. 53, 19–34 https://doi.org/10.1016/S1573-5214(05)80008-9.

Piccand, V., Cutullic, E., Meier, S., Schori, F., Kunz, P.L., Roche, J.R., Thomet, P., 2013. Production and reproduction of fleckvieh, Brown Swiss and 2 strains of holstein-friesian cows in a pasture-based, seasonal-calving dairy system. J. Dairy. Sci. 96, 5352–5363 https://doi.org/10.3168/jds.2012-6444.

Pryce, J.E., Woolaston, R., Berry, D.P., Wall, E., Winters, M., Butler, R., Shaffer, M., 2014. World trend in dairy cow fertility. http://www.wcgalp.org/system/files/proceedings/2014/world-trends-dairy-cow-fertility.pdf (assessed 27. July 2020).

Rae, R.C., Thomas, C., Reeve, A., Golightly, A.J., Hodson, R.G., Baker, R.D., 1987. The potential of an all-herbage diet for the late-winter calving dairy cows. Grass Forage Sci 42, 249–257 https://doi.org/10.1111/j.1365-2494.1987.tb02113.x.

Reist, M., Erding, D., von Euw, D., Tschuemperlin, K., Leuenberger, H., Chillard, Y., Hammon, H.M., Morel, C., Philipona, C., Zbinden, Y., Kuenzi, N., Blum, J.W., 2002. Estimation of energy balance at the individual and herd level using blood and milk traits in high-yielding dairy cows. J. Dairy Sci 85, 3314–3327 https://doi.org/10.3168/jds.s0022-0302(02)74420-2.

Roche, J.R., Friggens, N.C., Kay, J.K., Fisher, M.W., Stafford, K.J., Berry, D.P., 2009. Invited review: body composition score and its association with dairy cow productivity, health and welfare. J. Dairy Sci. 92, 5769–5801 https://doi: 10.3168/jds.2009-2431.

Schori, F., 2020a. Begrenzung der Proteinzufuhr in der Rindviehfütterung (Limiting the protein supply in cattle feeding), Agroscope, Posieux. https://doi.org/10.34776/as96g.

Schori, F., 2020b. Mit herbometer und pasturemeter die wuchshöhe von weiden messen und die grasmasse schätzen. Agrarforsch. Schweiz 11, 46–52.

Schori, F., Münger, A., 2014. Intake, feed conversion efficiency and grazing behaviour of two Holstein cow strains in a pasture-based production system under organic farming in Switzerland. Org. Agri. 4, 175–186 https://doi.org/10.1007/s13165-014-0066-2.

Sehested, J., Kristensen, T., Soegaard, K., 2003. Effect of concentrate supplementation level on production, health and efficiency in an organic dairy herd. Livest. Prod. Sci. 80, 153–165 https//doi.org/10.1016 /S0301-6226(02)00317-2.

Shalloo, L., Cromie, A., McHugh, N., 2014. Effect of fertility on the economics of pasture-based dairy systems. Animal 8 (s1), 222–232 https://doi:10.1017/S1751731114000615.

Spiekers, H., Hertel-Böhnke, P., Meyer, U., 2018. Verbundprojekt optiKuh, First ed., Bayrische Landesanstalt Für Landwirtschaft. Freising-Weihenstephan. https://www.optikuh.de/app/download/9959321368/verbundprojekt-optikuh-abschluss-2018_lfl-schriftenreihe.pdf?t=1580899761. accessed 7 Mai 2020.

Thanner, S., Schori, F., Bruckmaier, R.M., Dohme-Meier, F., 2014. Grazing behaviour, physical activity and metabolic profile of two Holstein strains in an organic grazing system. J. Anim. Physiol. Anim. Nutr. 98, 1143–1153 https://doi.org/10.1111/jpn.12172.

Wilkinson, J.M., 2011. *Re*-defining efficiency of feed use by livestock. Animal 5, 1014–1022 https://doi.org/10.1017/S175173111100005X.

Wilkinson, J.M., Lee, M.R.F., 2018. Review: use of human-edible animal feeds by ruminant livestock. Animal 12, 1735–1743 https://doi.org/10.1017/S175173111700218X.