



Effects of restricted periods of feed access on feed intake, digestion, behaviour, heat energy, and performance of Alpine goats

Nhayandra C. D. Silva, Ryszard Puchala, Terry A. Gipson, Tilahun Sahlu & Arthur L. Goetsch

To cite this article: Nhayandra C. D. Silva, Ryszard Puchala, Terry A. Gipson, Tilahun Sahlu & Arthur L. Goetsch (2018) Effects of restricted periods of feed access on feed intake, digestion, behaviour, heat energy, and performance of Alpine goats, Journal of Applied Animal Research, 46:1, 994-1003, DOI: [10.1080/09712119.2018.1450259](https://doi.org/10.1080/09712119.2018.1450259)

To link to this article: <https://doi.org/10.1080/09712119.2018.1450259>



© 2018 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group



Published online: 13 Mar 2018.



Submit your article to this journal [↗](#)



Article views: 326



View Crossmark data [↗](#)



Citing articles: 1 View citing articles [↗](#)

Effects of restricted periods of feed access on feed intake, digestion, behaviour, heat energy, and performance of Alpine goats

Nhayandra C. D. Silva^{a,b}, Ryszard Puchala^a, Terry A. Gipson^a, Tilahun Sahlu^a and Arthur L. Goetsch^a

^aAmerican Institute for Goat Research, Langston University, Langston, OK, USA; ^bDepartment of Animal Science, Universidade Estadual Paulista Julio de Mesquita Filho, Jaboticabal, Brazil

ABSTRACT

Fifty Alpine goats at 125 ± 3.0 days-in-milk were given access in Calan gate feeders to a 40% forage diet for 12 wk continuously (Control), during daytime (Day) or night (Night), or for 2 or 4 h/day after milking in the morning and afternoon (2Hour and 4Hour, respectively), resulting in few significant effects. In a second 12-wk experiment, average daily gain (ADG) by 40 Alpines at 14 ± 0.7 days-in-milk (73, 39, 11, 24, and 21 g) was greater for Control than for the average of other treatments, milk yield was similar among treatments, milk fat was lower ($P = .089$) for Control (3.41%, 3.88%, 4.21%, 3.70%, and 3.49%), and milk energy was not affected (8.20, 7.36, 9.53, 8.56, and 6.91 MJ/day for Control, 2Hour, 4Hour, Day, and Night, respectively). Metabolizable energy intake (31.25, 22.69, 25.92, 26.69, and 23.46 MJ/day) and heat energy (17.51, 13.34, 14.09, 15.54, and 15.25 MJ/day) were greater and milk energy relative to ME intake was lower for Control (26.0%, 31.9%, 37.6%, 31.4%, and 30.0% for Control, 2Hour, 4Hour, Day, and Night, respectively). In conclusion, continuous diet access of dairy goats in early to mid-lactation can affect partitioning of nutrients between milk synthesis and tissue accretion differently than some restricted feeder access treatments.

ARTICLE HISTORY

Received 9 January 2018
Accepted 26 February 2018

KEYWORDS

Behaviour; dairy goats; feed access

1. Introduction

In many confinement ruminant production systems, animals are allowed free and continuous access to total mixed diets. Although in some cases, the number of animals in a group can restrict eating time. For lactating dairy cattle, conditions facilitating at least 4 to 5 h/day of eating time allow productivity up to the genetic potential (Grant 2016). However, there have been some findings from studies with goats suggesting that efficiency of production could be greater with restricted periods of access (Berhan et al. 2005; Patra et al. 2008a, 2008b; Tovar-Luna et al. 2011; Tsukahara et al. 2014; Keli et al. 2017). As an example, in the study of Tsukahara et al. (2014), growing Boer goat wethers were given different periods of access to an automated feeder with a 50% concentrate pelleted diet. Continuous feeder access facilitated high average daily gain but resulted in relatively inefficient feed utilization as assessed by residual feed intake. Daytime feeder access decreased feed intake though increased efficiency of feed utilization. It is unclear if such findings might be directly relevant to conditions with lactating dairy goats. This may depend on factors responsible for relatively inefficient utilization of feed when feeder access was continuous such as relatively long time spent eating and high heat production when eating compared with that at other times (Osuji 1974; Sahlu et al. 2004).

Two of the restricted feed access treatments used by Tsukahara et al. (2014) of relevance to dairy goats in confinement or drylot-based production systems are access either during the day or night between milking times in the morning and afternoon. Other treatments of interest are 1- or 2-h access

periods after morning and afternoon milking for total daily feed access of 2 or 4 h/day, respectively, which would be convenient for management considerations such as close observation of feeding behaviour to monitor health conditions. In addition to production efficiency and other potential benefits, restricted feeder access regimes could facilitate production of a greater number of lactating goats with a given set of feeding facilities. In this regard, objectives of this study were to determine effects of different types of restricted feed access on feed intake, digestion, behaviour, heat energy (HE), and milk yield and composition of Alpine dairy goats in different stages of lactation.

2. Materials and methods

2.1. Experiment 1

2.1.1. Animals, treatments, and experimental design

Protocols for this and the subsequent experiment were approved by the Langston University Animal Care and Use Committee. Fifty Alpine goats (15 and 35 of parity 1 and ≥ 2 , respectively) with initial body weight (BW) of 55.2 kg (SEM = 0.95) and 125 days-in-milk (SEM = 3.0) were used. A 40% forage diet (Table 1) was given free-choice (120% of consumption on the preceding few days) in Calan gate feeders (American Calan Inc., Northwood, NH, USA) during a 2-wk preliminary or covariate period and subsequent 12-wk experiment that began on 24 August 2014, with four 3-wk periods. At the beginning of the preliminary period animals were orally treated for internal parasites with 0.75 mg/kg BW of moxidectin (Cydectin®;

Table 1. Diet composition.

Item	Concentration
Ingredient composition (% DM)	
Alfalfa hay (coarsely ground; 3.8-cm screen)	20.00
Cottonseed hulls	10.00
Grass hay (coarsely ground; 3.8-cm screen)	10.00
Wheat middlings	12.86
Oats (rolled)	12.86
Corn (rolled)	12.86
Soybean meal	10.99
Soybean oil	3.00
Molasses (liquid)	5.00
Limestone	0.93
Sodium bicarbonate	0.50
Ammonium sulphate	0.20
Magnesium oxide	0.20
Mineral supplement ^a	0.50
Vitamin premix ^b	0.05
Trace mineral mix ^c	0.05
Chemical composition (DM basis)	
Experiment 1 (mid- to late lactation) ^d	
Ash (%)	11.1 ± 0.17
Crude protein (%)	17.4 ± 0.43
Neutral detergent fiber (%)	40.6 ± 1.27
GE (MJ/kg)	20.6 ± 0.10
Experiment 2 (early to mid-lactation) ^e	
Ash (%)	10.4 ± 0.26
Crude protein (%)	16.6 ± 0.22
Neutral detergent fiber (%)	37.5 ± 0.35
Acid detergent fiber (%)	23.6 ± 0.47
Acid detergent lignin (%)	2.7 ± 0.04
GE (MJ/kg)	18.3 ± 0.04

^a35–40% NaCl, 9–10% Ca, and at least 6% P, 1% Mg, 1% K, 1% S, 125 mg/kg Co, 150 mg/kg I, 5000 mg/kg Fe, 10 mg/kg Se, 140 mg/kg Zn, 352,423 IU/kg vitamin A, 88,106 IU/kg vitamin D₃, and 330 IU/kg vitamin E.

^b8,800,000 IU/kg vitamin A, 1,760,000 IU/kg vitamin D₃, and 1100 IU/kg vitamin E.

^c275 mg/kg Co, 2000 mg/kg I, 43,746 mg/kg Fe, 750 mg/kg Se, 18,748 mg/kg Cu, 68,744 mg/kg Zn, and 19,998 mg/kg Mn.

^dMean ± SEM based on four composite samples for the 3-wk periods.

^eMean ± SEM based on three composite samples for the 4-wk periods.

Fort Dodge Animal Health, Fort Dodge, IA, USA) and 14 mg/kg BW of levamisole (Levasole®; Schering-Plough Animal Health, Union, NJ, USA).

The confinement facility, described by Patra et al. (2009), had 5.57 × 3.06 m pens. An area of 5.57 × 1.33 m at the front of each pen had an elevated expanded metal floor, with a flush manure system used once daily. Artificial lighting was provided from 06:00 to 17:00 h. Ambient temperature and relative humidity were determined every 30 min with three Hobo® Temperature/RH Data Loggers (model number U12-011; Onset Computer Corp., Bourne, MA, USA) placed in different areas of the facility.

The experiment was a randomized complete block design. Ten animals were allocated to each treatment based on parity (three and seven per treatment with parity of 1 and ≥ 2, respectively), BW, and milk yield during the preliminary period. Treatments were feed access continuously (Control), during the day for 8 h (Day) or night for 16 h (Night), or for 2 or 4 h/day with equal lengths after milking in the morning and afternoon (2Hour and 4Hour, respectively). Every 3 wk animals were moved to a different pen. Target times for milking were 08:20–08:40 and 16:20–16:40 h for Control, 07:40–08:00 and 16:00–16:20 h for Day, 08:00–08:20 and 15:40–16:00 h for Night, 07:20–07:40 and 15:20–15:40 h for 2Hour, and 07:00–07:20 and 15:00–15:20 h for 4Hour. Thus, times of feeder access were 08:40–16:20 and 16:40–08:20 h for Control, 08:00–16:00 h for Day, 16:00–08:00 h for Night, 07:40–08:40 and 15:40–16:40 h for 2Hour, and 07:20–09:20 and 15:20–17:20 h for 4Hour.

Electricity to the feeder access mechanism was regulated by Hobo® State/Pulse/Event/Runtime controllers (model number UX90-001; Onset Computer Corp., Bourne, MA, USA).

2.1.2. Measures

Milk yield was determined each day and milking. Milk samples were collected weekly during the preliminary period and on the last day of each 3-wk period. Samples were analysed for fat, protein, and lactose at the certified Dairy Herd Improvement Laboratory for Goats at Langston University with a MilkoScan 400 analyser (Foss Electric, Hillerød, Denmark). Somatic cell count (SCC) was determined with a Fossomatic 5000 analyser (Foss Electric). Both instruments were calibrated monthly. Milk energy concentration was determined by the equation of NRC (2001) based on concentrations of fat and protein, and milk yield was adjusted to 3.5% fat and 3.2% protein as well. BW was recorded at the beginning and end of the preliminary and 3-wk experimental periods. Average daily gain was estimated by regressing BW against day. Body condition score (BCS) was estimated by three individuals as described by Ngwa et al. (2007) at the beginning and end of the experiment.

Feed was sampled weekly and a composite sample was formed for each period. Canvas bags with perforated bottoms to allow urine drainage were used to collect total faeces excreted over 5 days from five animals per treatment in both wk 6 and 7 (i.e. 25 per wk). After weighing faeces daily, a 10% aliquot sample was saved to form a composite that was kept frozen between and after days of sampling. Refused feed was sampled on days when faeces were collected to form composite samples for each animal. Feed and ort samples were dried at 55°C in a forced-air oven. Samples were ground to pass a 1-mm screen and analysed for dry matter (DM), ash (AOAC 2006), crude protein (CP) (Leco TruMac CN, St. Joseph, MI, USA), neutral detergent fiber (NDF) with use of heat stable amylase and containing residual ash (filter bag technique of ANKOM Technology Corp., Fairport, NY, USA), and gross energy (GE) using a bomb calorimeter (Parr 6300; Parr Instrument Co., Inc., Moline, IL, USA; AOAC 2006). Intake of metabolizable energy (ME) was determined as 82% of digestible energy (DE) intake (NRC 1984).

HE was determined by use of heart rate (HR) for prediction, as described by Puchala et al. (2007, 2009). During the middle week of each period on days 2 and 4, HR was recorded for 24 h, with measurements first on five animals per pen and then on the second five animals. The animals were fitted with 10 × 10 cm electrodes prepared from stretch conductive fabric (Less EMF, Albany, NY, USA), glued to Vermed PerformancePlus electrocardiogram (ECG) electrodes (Bellows Falls, VT, USA) and attached to the chest just behind and slightly below the left elbow and behind the shoulder blade on the right side. Electrodes were connected by ECG snap leads (Bioconnect, San Diego, CA, USA) to T61 coded transmitters (Polar, Lake Success, NY, USA). Human S610 HR (Polar) monitors with a wireless connection to the transmitters were used to collect HR data at a 1-min interval. HR data were analysed using Polar Precision Performance SW software. At the same time as HR was being recorded, animals were fitted on the rear left leg with an IceTag leg activity monitor (IceRobotics Limited, Midlothian, Scotland, UK) to measure time spent standing and lying.

After the experimental period, over an additional 2 wk, the ratio of HE to HR was determined for 24 h following 1 day of adaptation to housing in an adjacent room in four metabolism crates fitted with head-boxes of an indirect, open-circuit respiration calorimetry system (Sable Systems International, North Las Vegas, NV, USA). The feed access treatments continued to be imposed during this period. Measures were similar to those in previous studies (Puchala et al. 2007, 2009). Oxygen concentration was measured using a fuel cell FC-1B O₂ analyser (Sable Systems International), and CH₄ and CO₂ concentrations were measured with infrared analysers (CA-1B for CO₂ and MA-1 for CH₄; Sable Systems International). Prior to gas exchange measurements, analysers were calibrated with gases of known concentrations. Ethanol combustion tests were performed to ensure complete recovery of O₂ and CO₂ produced with the same flow rates as used during measurements. HE was determined according to the Brouwer (1965) equation without consideration of urinary N. HR measured during the experimental period was multiplied by the ratio of HE to HR measured in these subsequent 2 wk to estimate earlier HE.

During wk 4 and 10, two communication cameras (VC-C50iR; Canon U.S.A., Inc., Lake Success, NY, USA) were mounted in the rafters above each pen to record activity of animals over 2 days. The cameras were equipped with infrared capabilities to render black and white images throughout all hours of the days and were boosted by two infrared illuminators (VT-IR2-110 LED IR Illuminator, Vitek Industrial Video Products, Inc., Valencia, CA, USA) with a 30.5-m range mounted above each pen. Due to the size of the pens and the limiting height of the rafters, the cameras were situated to record the front area of the pens where the feeders and elevated flooring were rather than the whole pen including the lower concrete floor area. Recordings (Mpeg) were coded using the Observer XT Version 10.5 (Noldus Information Technology, Wageningen, The Netherlands). Coded variables were eating vs. not eating, situation in the area with the elevated flooring next to the Calan gate feeders, and unsuccessful attempts to open the Calan gate.

Blood samples (10 ml) were collected from a jugular vein using heparinized tubes on the last day of the preliminary period and the four 3-wk periods of the experiment. Blood samples were stored in ice for approximately 1 h until they were processed. Plasma was harvested by centrifugation at 3000 × *g* for 20 min and analysed in triplicate for leptin and insulin-like growth factor 1 IGF-1 by double antibody radio-immunoassays validated by Powell and Keisler (1995), Delavaud et al. (2000), and Morrison et al. (2002). Inter- and intra-assay coefficients of variation were less than 8%.

2.1.3. Statistical analyses

Data were analysed by mixed effects models with the Statistical Analysis System (Littell et al. 1996; SAS 2011). Log-transformed SCC was statistically analysed. The model for variables with one value, such as ADG and digestibilities, consisted only of treatment with animal as random. For variables with values in each period, fixed effects were treatment, period, treatment × period, and values in the preliminary period were used as covariates; period was repeated measure with the random effect of animal. Parity (1 and ≥ 2) was not included in models because of nonsignificant interactions with treatment. Primary interest was

in treatment effects, with any interactions between treatment and period difficult to explain given that the experiment was 12 wk in length. Therefore, the main effect means for treatment and period are presented in tables regardless of the significance of the interaction. Means separation was by the least significant difference with a protected *F*-test. A contrast of the Control treatment vs. the mean of restricted feeder access treatments, as used in experiment 2, was evaluated but not included since few *P* values were significant and interpretation as not aided.

2.2. Experiment 2

Procedures were very similar to those of experiment 1, which will be briefly overviewed here with an emphasis on differences. Forty Alpine goats (12 and 28 of parity 1 and ≥ 2, respectively) with initial BW of 58.0 kg (SEM = 1.50) and 14.2 days-in-milk (SEM = 0.72; range of 9–22) were used. The same diet (Table 1) was given free-choice in Calan gate feeders during the 12-wk trial that began on 31 March 2015. Treatments and milking times were as described earlier. Eight animals were allocated to each treatment based on kidding date and parity. The experiment consisted of three 4-wk periods. Animals were moved to a different pen every 4 wk.

Milk samples were collected on the last day of each 4-wk period. BW was measured at the beginning of the study and end of the periods. Faecal output was determined over 5 days from four animals per treatment in wk 7 and the other animals in wk 8. In addition to the aforementioned analyses, feed samples were analysed for acid detergent fibre and lignin (filter bag technique of ANKOM Technology Corp.).

HE was determined based on HR measured in wk 8 and 11 (periods 2 and 3, respectively), with measurements first on four animals per pen and then on the second four animals. After the experimental period, over an additional 2 wk, the ratio of HE to HR was determined for 24 h after 1 day of adaptation to housing in an adjacent room in four metabolism crates fitted with head-boxes of an indirect, open-circuit respiration calorimetry system. Behaviour and blood constituent levels were not evaluated. Data were statistically analysed as in experiment 1. Means separation was by a contrast of the Control treatment vs. the mean of restricted feeder access treatments and the least significant difference with a protected *F*-test for restricted access treatments.

3. Results

3.1. Experiment 1

3.1.1. Diet composition and temperature and humidity

The dietary CP concentration (Table 1) was greater than the requirement (NRC 2007), and the level of NDF was above that needed by dairy cattle for normal rumen function (NRC 2001). Relatedly, the dietary level of NDF was slightly greater than expected based on tabular feedstuff levels of Preston (2015). Temperature and the temperature–humidity index (THI; Amundson et al. 2006) decreased as the experiment progressed, without marked change in relative humidity (Table 2). Although the thermoneutral zone of lactating dairy

Table 2. Average daily temperature (T), relative humidity (RH), and THI in the facility.

Experiment ^a	Period	Item ^b	Mean	SEM	Minimum	Maximum
1	1	Temperature (°C)	26.5	2.95	17.9	29.2
		Relatively humidity (%)	62.9	3.54	54.4	68.6
		THI	75.0	4.08	62.7	78.9
	2	Temperature (°C)	23.2	2.22	19.3	26.6
		Relatively humidity (%)	64.5	4.86	56.8	73.8
		THI	70.5	3.56	64.4	76.0
	3	Temperature (°C)	19.3	2.89	15.9	25.2
		Relatively humidity (%)	63.3	3.38	55.3	68.4
		THI	64.8	4.06	60.0	73.1
	4	Temperature (°C)	14.0	2.87	8.8	19.6
		Relatively humidity (%)	57.6	6.92	45.6	73.4
		THI	57.3	3.80	50.8	64.7
2	1	Temperature (°C)	19.5	0.11	14.3	26.5
		Relatively humidity (%)	61.1	0.48	27.0	85.2
		THI	65.2	0.16	57.8	75.3
	2	Temperature (°C)	20.4	0.10	14.3	26.3
		Relatively humidity (%)	69.4	0.43	47.8	89.7
		THI	66.8	0.14	57.7	75.2
	3	Temperature (°C)	26.2	0.12	18.4	32.3
		Relatively humidity (%)	70.0	0.28	48.2	83.6
		THI	75.5	0.15	64.1	82.2

^aExperiment 1 was in mid- to late lactation, with 3-wk periods beginning August 24, 2014; Experiment 2 was in early to mid-lactation, with 4-wk periods beginning March 31, 2015.

^bTHI = $(0.8 \times T) + (RH \times ((T - 14.3)/100)) + 46.3$.

goats is not well established, it would seem that the animals were not subjected to heat or cold stress conditions (Silanikove & Koluman 2015).

< 3 < 2, with the value in period 4 not different from those of periods 2 and 3. The IGF-1 concentration was greater in periods 3 and 4 than in periods 1 and 2 ($P < .05$).

3.1.2. Feed intake, daily behaviour, and plasma hormone levels

Intake of DM was not affected by treatment or period ($P > .05$; Table 3). Treatment did not have an effect on time spent standing, active, or lying, although period had influence ($P < .05$). Time eating was greatest among treatments ($P < .05$) for Control and lower for 2Hour vs. Day and Night ($P < .05$). Time spent near feeders was lower ($P < .05$) for 2Hour than for all treatments but Night. The number of unsuccessful attempts to enter feeders was not affected by treatment or period ($P > .05$).

The plasma leptin concentration was lower for Day than for 2Hour and Night ($P < .05$) and greater for Night vs. 4Hour ($P < .05$; Table 3). The level of IGF-1 was similar among treatments ($P > .05$). Concentrations of both leptin and IGF-1 varied with period ($P < .05$). The leptin level ranked ($P < .05$) period 1

3.1.3. Milk composition and yield

Milk fat concentration was lower for 4Hour ($P < .05$) than for all treatments except Night (Table 4). Concentrations of protein and lactose were lowest among treatments for 4Hour ($P < .05$). Concentrations of fat and protein ranked ($P < .05$) period 1 < 2 < 3 < 4, although lactose concentration was similar among periods ($P > .05$). The SCC was not influenced by treatment or period ($P > .05$). Raw milk yield was similar among treatments ($P > .05$) and greater in periods 1 and 2 than 3 and 4 ($P < .05$; Table 4). Yields of all milk components significantly or numerically ranked 4Hour < 2Hour, Day, and Night < Control.

There were both treatment and period effects ($P < .05$) on adjusted milk yield because of differences in milk component levels (Table 4). Adjusted milk yield was greater for Control and Day than for 4Hour ($P < 0.05$). Values for 2Hour and Night

Table 3. Feed intake, behavior, and plasma hormone concentrations for Alpine goats in mid- to late lactation (experiment 1).

Item ¹	Treatment ²					SEM	Period ³				SEM
	Control	2Hour	4Hour	Day	Night		1	2	3	4	
DM intake (g/day)	2065	1914	1909	1874	2099	104.2	1948	2023	1915	2004	57.3
Behavior											
Standing (% day)	53.4	48.8	48.2	43.9	57.5	3.63	50.9 ^b	34.3 ^a	51.7 ^b	64.6 ^c	2.50
Active (% day)	3.9	3.8	3.1	3.8	3.8	0.21	3.6 ^b	2.9 ^a	4.1 ^c	4.1 ^c	0.21
Lying (% day)	42.6	47.4	48.7	52.2	38.8	3.74	45.5 ^b	62.8 ^c	44.2 ^b	31.3 ^a	2.60
Eating (% day)	35.9 ^c	7.7 ^a	13.1 ^{ab}	20.2 ^b	17.7 ^b	3.05		19.3		18.5	1.64
Near feeders (% day)	72.0 ^b	56.8 ^a	68.3 ^b	74.7 ^b	67.0 ^{ab}	4.00		63.0 ^a		72.5 ^b	3.98
Unsuccessful feeder entry attempts	7.2	7.9	8.0	9.6	7.7	0.89		7.7		8.4	0.51
Leptin (ng/ml)	10.1 ^{abc}	10.4 ^{bc}	7.8 ^{ab}	6.7 ^a	11.9 ^c	1.26	7.4 ^a	10.6 ^c	9.1 ^b	10.5 ^{bc}	0.71
IGF-1 (ng/ml)	127	118	119	125	119	4.5	112 ^a	118 ^a	129 ^b	128 ^b	3.1

¹Insulin-like growth factor 1.

²Control = continuous feed access other than during milking; Day = feed access during the day for 8 h; Night = feed access during the night for 16 h; 2Hour = feed access for 1 h after the morning milking and 1 h after the afternoon milking; 4Hour = feed access for 2 h after the morning milking and 2 h after the afternoon milking.

³3-wk periods.

^{a,b}Main effect means in a row without a common superscript letter differ ($P < .05$).

Table 4. Milk composition and yield for Alpine goats in mid- to late lactation (experiment 1).

Item	Treatment ¹					SEM	Period ²				SEM
	Control	2Hour	4Hour	Day	Night		1	2	3	4	
Milk concentration (%)											
Fat	3.80 ^b	3.78 ^b	3.20 ^a	3.63 ^b	3.53 ^{ab}	0.132	2.99 ^a	3.45 ^b	3.76 ^c	4.14 ^d	0.084
Protein	2.91 ^b	2.84 ^b	2.57 ^a	2.88 ^b	2.88 ^b	0.049	2.54 ^a	2.66 ^b	2.88 ^c	3.18 ^d	0.028
Lactose	4.34 ^c	4.18 ^b	3.88 ^a	4.25 ^b	4.23 ^b	0.026	4.19	4.14	4.20	4.18	0.020
SCC	1826	1941	1865	2138	1882	295.0	1700	2209	1804	2008	1762
Milk yield (g/day)											
Fat	73 ^c	62 ^{bc}	51 ^a	63 ^{bc}	59 ^{ab}	4.1	55 ^a	64 ^{bc}	61 ^b	66 ^c	2.3
Protein	52 ^b	47 ^{ab}	41 ^a	52 ^b	49 ^b	2.6	47 ^a	50 ^b	46 ^a	50 ^b	1.3
Lactose	80 ^b	72 ^{ab}	62 ^a	77 ^b	75 ^b	4.0	79 ^b	78 ^b	69 ^a	67 ^a	2.0
Raw (g/day)	1845	1710	1594	1820	1756	93.2	1869 ^b	1879 ^b	1638 ^a	1593 ^a	47.3
Adjusted ³											
g/day	1907 ^b	1684 ^{ab}	1436 ^a	1760 ^b	1662 ^{ab}	91.5	1633 ^a	1772 ^b	1634 ^a	1720 ^b	48.3
g/kg DM intake	872	834	834	926	835	61.2	848	879	861	874	33.21

¹Control = continuous feed access other than during milking; Day = feed access during the day for 8 h; Night = feed access during the night for 16 h; 2Hour = feed access for 1 h after the morning milking and 1 h after the afternoon milking; 4Hour = feed access for 2 h after the morning milking and 2 h after the afternoon milking.

²3-wk periods.

³3.5% fat and 3.2% protein.

^{a,b,c}Main effect means in a row without a common superscript letter differ ($P < .05$).

were not different from those for Control, Day, or 4Hour ($P > .05$). Despite the differences among treatments and periods in adjusted milk yield and no treatment or period difference in DM intake, the ratio of adjusted milk yield to DM intake was similar among treatments and periods ($P > .05$).

3.1.4. ADG, BCS, HE:HR, and energy measures

Average daily gain, digestibilities, and the ratio of HE to HR were similar among treatments ($P > .05$; Table 5). Initial BCS was 2.29 (SEM = 0.032) and change during the experiment was similar among treatments ($P > .05$). HR was lower for 2Hour and 4Hour than for other treatments ($P < .05$) and greater for Night vs. Day ($P < .05$; Table 6). Differences in HE in kJ/kg BW^{0.75} were the same, except that values for Control, Day, and Night were similar ($P > .05$). HE in MJ/day was lower for 2Hour and 4Hour than for Night ($P < .05$). Both DE and ME intakes did not differ among treatments ($P > .05$). Differences among treatments and periods in MJ/day of milk energy were the same as those in g/day of adjusted milk yield. Treatment did not affect milk energy in kJ/kg BW^{0.75}, with values greater in periods 2 and 4 than in periods 1 and 3 ($P < .05$). Neither treatment nor period affected milk energy relative to ME intake ($P > .05$).

Table 5. Average daily gain, BCS, digestibility, and heat energy:heart rate (HE:HR) for Alpine goats in mid- to late lactation (experiment 1).

Item	Treatment ^a					SEM
	Control	2Hour	4Hour	Day	Night	
Average daily gain (g)	32	9	20	22	49	13.0
BCS change	0.18	0.06	0.11	0.12	0.03	0.071
Digestibility (%)						
DM	63.1	66.4	69.5	72.2	67.8	2.32
Organic matter	64.6	68.1	71.2	73.7	69.2	2.27
Crude protein	72.7	74.9	76.8	79.6	75.3	1.78
Neutral detergent fiber	47.9	54.8	56.6	61.1	54.7	3.53
GE	70.4	74.3	76.1	77.2	73.6	1.97
HE:HR (kJ/kg BW ^{0.75} per heart beat/min)	6.43	6.98	6.65	6.94	6.91	0.279

^aControl = continuous feed access other than during milking; Day = feed access during the day for 8 h; Night = feed access during the night for 16 h; 2Hour = feed access for 1 h after the morning milking and 1 hour after the afternoon milking; 4Hour = feed access for 1 h after the morning milking and 1 h after the afternoon milking; 4Hour = feed access for 2 h after the morning milking and 2 h after the afternoon milking.

3.2. Experiment 2

3.2.1. Diet composition and temperature and humidity

The chemical composition of the diet was fairly similar to that in experiment 1, although levels of CP, NDF, and GE were slightly less than in experiment 1 (0.8 percentage units, 3.1 percentage units, and 2.3 MJ/kg, respectively; Table 2). Temperature and THI in periods 1 and 2 were similar and less than in period 3.

3.2.2. Feed intake and milk composition and yield

Average DM intake during the entire experiment (Table 7) was greater for Control than for the average of limited feeder access treatments ($P = .004$). The concentration of fat in milk tended ($P = .089$) to be lower for Control than for the mean of restricted feeder access treatments. An overall treatment P of .070 also related to a relatively high value for 4Hour treatment and low concentration for Control. The fat concentration ranked ($P < .05$) period 1 > 2 > 3, the level of protein was similar among treatments ($P > .05$) but greatest among periods ($P < .05$) in period 1, and the concentration of lactose was not affected ($P > .05$) by treatment or period. The SCC tended ($P = .053$) to be greater for Control than for the mean of restricted feeder access treatments and was greater ($P < .05$) in period 1 than in periods 2 and 3.

There were no treatment effects in yield of any milk component ($P > .05$); however, there were period effects for all variables (Table 7). Fat yield ranked ($P < .05$) period 1 > 2 > 3 and yield of protein was greater ($P < .05$) in period 1 than 3, with an intermediate value ($P > .05$) for period 2 in accordance with differences in concentrations. Raw and adjusted milk yields were not influenced by treatment ($P > .10$), although both differed among periods ($P \leq .02$). Adjusted milk yield was greater in periods 1 and 2 than in period 3 ($P < .05$). The ratio of adjusted milk yield to DM intake tended ($P = .065$) to be less for Control than for the mean of restricted feeder access treatments and numerically was greatest for 4Hour, averaging 0.28 kg/kg DM intake and 28% greater than for 2Hour, Day, and Night. The ratio varied among periods ($P < .001$), ranking ($P < .05$) period 1 > 2 > 3.

Table 6. Energy measures for Alpine goats in mid- to late lactation (experiment 1).

Item ¹	Treatment ²					SEM	Period ³				SEM
	Control	2Hour	4Hour	Day	Night		1	2	3	4	
HR (beats/min)	99.5 ^{bc}	85.7 ^a	84.0 ^a	95.3 ^b	101.4 ^c	1.87	91.6 ^{ab}	94.1 ^{bc}	90.4 ^a	96.5 ^c	1.29
HE											
kJ/kg BW ^{0.75}	640 ^{ab}	597 ^a	559 ^a	663 ^{ab}	696 ^b	27.1	621 ^{ab}	636 ^{bc}	613 ^a	653 ^c	13.9
MJ/day	13.24 ^{ab}	11.93 ^a	11.64 ^a	13.49 ^{ab}	14.46 ^b	0.673	12.59 ^a	13.07 ^{ab}	12.62 ^a	13.52 ^b	0.338
DE (MJ/day)	29.27	28.27	30.30	31.12	31.91	1.972	29.69	31.25	29.63	30.14	1.020
ME											
MJ/day	24.00	23.18	24.85	25.52	26.17	1.617	24.34	25.62	24.29	24.71	0.836
kJ/kg BW ^{0.75}	1181	1159	1189	1240	1253	71.8	1197	1248	1182	1190	37.7
Milk energy (% ME intake)											
MJ/day	5.38 ^c	4.68 ^b	3.91 ^a	4.91 ^{bc}	4.63 ^{ab}	0.258	4.53 ^a	4.91 ^b	4.56 ^a	4.81 ^b	0.136
kJ/kg BW ^{0.75}	265 ^c	228 ^{ab}	194 ^a	241 ^{bc}	227 ^{ab}	12.3	222 ^a	241 ^b	224 ^a	236 ^b	6.6
% ME intake	19.9	20.7	17.7	18.4	18.9	1.98	18.7	19.3	18.7	19.8	0.97

¹ME = metabolizable energy.²Control = continuous feed access other than during milking; Day = feed access during the day for 8 h; Night = feed access during the night for 16 h; 2Hour = feed access for 1 h after the morning milking and 1 h after the afternoon milking; 2Hour = feed access for 1 h after the morning milking and 1 h after the afternoon milking; 4Hour = feed access for 2 h after the morning milking and 2 h after the afternoon milking.³3-wk periods.^{a,b,c}Main effect means in a row without a common superscript letter differ ($P < .05$).

3.2.3. Initial BW, ADG, BCS, digestibilities, and HE:HR

Initial BW was similar among treatments ($P > .05$; Table 8). Although, perhaps because animals were allocated to treatments based on kidding date, BW was numerically lowest for Night. Average daily gain was greater ($P = .019$) for Control than for the mean of restricted feeder access treatments. Initial BCS was 2.45 (SEM = 0.022) and the magnitude of decline during the experiment tended ($P = .067$) to be less for Control than for the mean of restricted feeder access treatments. Digestibilities and the ratio of HE to HR were similar among treatments ($P > .05$).

3.2.4. Energy measures

HR was greater ($P = .013$) for Control than for the mean of restricted feeder access treatments and greater ($P < .05$) for Control and Night than for 2Hour and 4Hour (Table 9). Intake of ME was greater for the Control treatment than for the mean of restricted feeder access treatments in MJ/day ($P = .011$) and

kJ/kg BW^{0.75} ($P = .008$). Milk energy in MJ/day and kJ/kg BW^{0.75} varied in accordance with yield of milk adjusted for fat and protein concentrations. Milk energy as a percentage of ME intake tended to be less for Control than for the mean of restricted feeder access treatments ($P = .057$), and the overall treatment P value was 0.143. Nonetheless, numerically the value was greatest for 4Hour (i.e. differences of 5.7, 6.2, and 7.6 percentage units relative to 2Hour, Day, and Night, respectively).

4. Discussion

4.1. Experiment 1

4.1.1. Feed intake and digestion

The diet could be considered of high quality given the 60% level of concentrate feedstuffs and inclusion of soybean oil at 3%. It was formulated to create conditions conducive to potential acceptable performance with limited feed access treatments rather than the use of a low-quality diet higher in forage that

Table 7. Feed intake and concentration and yield of milk constituents for Alpine goats in early to mid-lactation (experiment 2).

Table 1. DM intake and concentration of milk of milk concentrates for dairy goats in early to mid lactation (Experiment 2).											
Item	Contrast ¹	Treatment ²					SEM	Period ³			
		Control	2Hour	4Hour	Day	Night		1	2	3	SEM
DM intake (g/day)	0.004	2695	2067	2231	2331	2008	157.1	2090 ^a	2299 ^b	2411 ^c	76.4
Milk concentration											
Fat (%)	0.089	3.41	3.88	4.21	3.70	3.49	0.208	4.30 ^c	3.64 ^b	3.27 ^a	0.123
Protein (%)	0.378	2.58	2.69	2.69	2.67	2.55	0.071	2.83 ^b	2.55 ^a	2.53 ^a	0.046
Lactose (%)	0.981	4.39	4.38	4.41	4.42	4.38	0.045	4.38	4.42	4.38	0.026
Energy (MJ/kg)	0.105	2.64	2.85	2.98	2.78	2.66	0.094	3.04 ^c	2.73 ^b	2.57 ^a	0.056
SCC (number/ml)	0.053	2791	2212	1668	2293	1560	718.4	3310 ^b	1688 ^a	1317 ^a	525.4
Milk yield (g/day)											
Fat (g/day)	0.895	108	100	134	115	91	15.3	122 ^c	111 ^b	95 ^a	7.3
Protein (g/day)	0.764	79	69	86	81	66	9.7	79 ^b	77 ^{ab}	73 ^a	4.5
Total solids (g/day)	0.842	332	294	376	343	278	42.0	309 ^a	345 ^b	319 ^a	19.4
Raw (g/day)	0.678	3046	2596	3235	3070	2580	374.9	2780 ^a	3029 ^b	2907 ^{ab}	172.1
Adjusted ⁴											
g/day	0.918	2913	2610	3374	3033	2459	379.8	3039 ^b	2934 ^b	2660 ^a	176.9
kg/kg DM intake	0.065	1.06	1.23	1.53	1.27	1.24	0.119	1.44 ^c	1.27 ^b	1.09 ^a	0.059

¹ P value for Control vs. mean of restricted feed access treatments.²Control = continuous feed access other than during milking; Day = feed access during the day for 8 h; Night = feed access during the night for 16 h; 2Hour = feed access for 1 h after the morning milking and 1 h after the afternoon milking; 2Hour = feed access for 1 h after the morning milking and 1 h after the afternoon milking; 4Hour = feed access for 2 h after the morning milking and 2 h after the afternoon milking.³3-wk periods.⁴3.5% fat and 3.2% protein.^{a,b,c}Period means without a common superscript letter differ ($P < .05$).

Table 8. Average daily gain, BCS, intake, digestibility, and heat energy:heart rate (HE:HR) for Alpine goats in early to mid-lactation (experiment 2).

Item	Contrast ^a	Treatment ^b					SEM
		Control	2Hour	4Hour	Day	Night	
Initial BW (kg)	0.870	57.4	59.9	59.3	58.7	54.3	3.45
Average daily gain (g)	0.019	73	39	11	24	21	17.7
BCS change	0.067	−0.22	−0.29	−0.35	−0.42	−0.33	0.062
Digestibility (%)							
DM	0.650	74.7	70.6	74.9	74.0	75.1	2.00
Organic matter	0.574	77.1	73.1	76.9	76.3	77.3	1.81
Neutral detergent fiber	0.358	54.8	44.7	52.9	53.4	50.7	4.20
Crude protein	0.881	80.7	78.7	82.8	79.6	82.6	1.55
GE	0.733	76.6	72.9	77.3	76.0	77.6	1.84
HE:HR (kJ/kg BW ^{0.75} per heart beat/min)	0.606	7.10	6.67	7.18	6.96	6.86	0.309

^a*P* value for Control vs. mean of restricted feed access treatments.

^bControl = continuous feed access other than during milking; Day = feed access during the day for 8 h; Night = feed access during the night for 16 h; 2Hour = feed access for 1 h after the morning milking and 1 hour after the afternoon milking; 4Hour = feed access for 2 h after the morning milking and 2 h after the afternoon milking.

would necessitate a long time spent eating to avoid low ME intake. Although the level of NDF was considerably above minimum levels recommended for dairy cattle (NRC 2001) as noted above, because of the treatments with short lengths of access, particularly 2Hour, sodium bicarbonate was included as a precaution to limit risk of ruminal acidosis and digestive upset.

The lack of effect of treatment on digestibilities may reflect the relatively high quality of the diet and suggests that digesta passage rate was not markedly affected by restricted feed access treatments. Energy digestibility means are slightly greater than expected given the ingredient composition (e.g. TDN concentration of 72.5% based on values of Preston 2015), which could be the result of some loss of DM from faecal bags because of urine drainage.

No treatment differences in feed intake reflect the capacity for high rates of consumption per unit time possible with a diet such as the one used and the ability of dairy goats to adapt to very different feeding practices. For example, the rate of DM intake based on daily averages of DM intake in the four periods and eating time during the two measurement periods was highest among treatments (*P* < .05) for 2Hour and greater (*P* < .05) for 4Hour than for Control and Day (4.9, 17.7, 12.2, 7.5, and 8.8 g/min for Control, 2Hour, 4Hour, Day, and Night, respectively; SEM = 1.48). Though the value for 2Hour was relatively high, greater values (i.e. 20.7 to 24.6 g/min) have been noted with

pelleted diets consumed by growing meat goats (Gipson et al. 2006, 2007; Tsukahara et al. 2014). Differences in rate of DM intake between pelleted and loose (unpelleted) diets noted by Gipson et al. (2007; 24.6 and 22.0 vs. 12.9 and 13.7 g/min) may partially explain the lower values in the present experiment for most treatments, although those for the loose diets still are much greater than Control, Day, and Night treatment values. Perhaps, one Calan gate feeder per animal compared with sharing of an automated feeding unit in these previous studies contributed to the differences as well.

4.1.2. Milk yield and component levels

There are no reasons readily apparent for low milk concentrations of fat, protein, and lactose for the 4Hour animals. This would not seem related to the length of time between morning and afternoon milkings of 8, 8, 8.33, and 7.67 h for 2Hour, 4Hour, Control, Day, and Night, respectively. Perhaps these findings involve milking 4Hour goats first both in the morning and afternoon, but exactly how this could have had influence is unclear. The difference would not seem related to animal allocation to treatments because of covariate analysis. However, neither the ratio of adjusted milk yield to DM intake nor milk energy as a percentage of ME intake varied with treatment.

Table 9. Energy measures for Alpine goats in early to mid-lactation (experiment 2).

Item	Contrast ¹	Treatment ²					SEM	Period ³			SEM
		Control	2Hour	4Hour	Day	Night		1	2	3	
HR (beats/min)	0.013	108	93	95	102	110	2.8		102	101	1.3
Metabolizable energy intake											
MJ/day	0.011	31.25	22.69	25.92	26.69	23.46	2.184	23.95	26.37	27.69	1.036
kJ/kg BW ^{0.75}	0.008	1417	1054	1218	1242	1149	79.9	1138	1229	1282	38.4
HE											
kJ/kg BW ^{0.75}	0.007	790	618	662	709	749	29.7		708	704	13.5
MJ/day	0.003	17.51	13.34	14.09	15.54	15.25	0.921		15.12	15.18	0.417
Milk energy											
MJ/day	0.928	8.20	7.36	9.53	8.56	6.91	1.071	8.59 ^b	8.27 ^b	7.47 ^a	0.499
kJ/kg BW ^{0.75}	0.698	375	339	446	393	339	46.9	403 ^b	386 ^b	346 ^a	21.9
% ME intake	0.057	26.0	31.9	37.6	31.4	30.0	3.08	35.6 ^c	31.5 ^b	27.0 ^a	1.51

¹*P* value for Control vs. mean of restricted feed access treatments.

²Control = continuous feed access other than during milking; Day = feed access during the day for 8 h; Night = feed access during the night for 16 h; 2Hour = feed access for 1 h after the morning milking and 1 h after the afternoon milking; 4Hour = feed access for 2 h after the morning milking and 2 h after the afternoon milking.

³3-wk periods.

^{a,b,c}Period means without a common superscript letter differ (*P* < .05).

4.1.3. HE and hormones

Tendencies for HE to be less for 2Hour and 4Hour than for Control, Day, and Night treatments is somewhat in agreement with findings of Tsukahara et al. (2014) for Boer goats. In that study, continuous feeder access resulted in high ADG but relatively inefficient feed utilization, which was thought to be associated with longer total time spent in the automated feeders than goats with restricted feeder access regimes. However, the correlation between experiment averages of HE relative to $BW^{0.75}$ and eating time in the present experiment was low and only tended to be significant ($r = 0.26$; $P = .072$).

Treatment differences in concentrations of leptin and differences among periods in levels of both leptin and IGF-1 do not seem to closely coincide with treatment differences or lack thereof in other variables such as ME intake, milk energy, and ADG. However, there were some low but significant correlations observed. Relationships were noted between leptin and milk energy ($r = -0.23$; $P = .001$) and ADG ($r = 0.20$; $P = .005$) and between IGF-1 and ADG ($r = 0.14$; $P = .042$). Moreover, leptin and IGF-1 levels tended to be related ($r = 0.13$; $P = .076$).

4.1.4. Behaviour

The animals quickly learned when their feed trough would be accessible and generally attempted to open the Calan gate only slightly before access was allowed. They rarely attempted to open the gate during periods of no access. This is exemplified by the lack of marked and consistent differences among treatments in the number of unsuccessful feeder entry attempts. Relatedly, that 2Hour animals spent more time away from their feeders may reflect knowledge that feeder access was not possible other than during the two 1-h periods after milking.

As alluded to above, time spent eating relative to access time was 38%, 92%, 77%, 61%, and 27% for Control, 2Hour, 4Hour, Day, and Night, respectively. The similar total length of time spent eating for Day and Night, yet feeder access time twice as great for Night, depicts the normal greater propensity for eating during the day than night.

4.1.5. Overall effects

In contrast to findings of Tsukahara et al. (2014) with growing meat goat wethers, clear benefits in terms of level or efficiency of production from limited feeder access treatments were not readily apparent. The results also disagree slightly with those of Keli et al. (2017). In that experiment, lactating dairy goats were allowed to graze pastures continuously or between the morning and afternoon milkings or when leaf surfaces were dry until the afternoon milking or sunset. It appeared that animals given continual pasture access had greatest HE because of more time spent grazing as well as an increased basal metabolic rate compared with other treatments, particularly set pasture access each day between milking times in the morning and afternoon. Nonetheless, it is notable that limited feeder access treatments in the present experiment, primarily 2Hour, did not adversely affect performance. In this regard, for lactating dairy cattle it is commonly assumed that 4–5 h/day is spent eating and necessary for greatest and most efficient performance with typical diets allowing

maximal performance of high-yielding breeds, namely Holstein (Grant 2016). However, that allowance is for group-fed cows with a minimum of bunk space, in contrast to conditions in the present experiment where each animal had its own feeder and did not have to compete with others.

4.2. Experiment 2

4.2.1. Digestion and feed intake

The lack of treatment effects on digestibilities agrees with findings of experiment 1. Even with short periods of feeder access, mastication of a diet of this nature is adequate for particle size reduction and plant tissue disruption necessary to facilitate thorough microbial attachment and digestion before ruminal digesta outflow.

It is not clear why DM intake was greater for the Control than for restricted access treatments and this was not observed in experiment 1. Perhaps this involves the earlier stage of lactation, with higher DM intake relative to BW for the Control, 4Hour, and Day treatments. Highest DM intake may have necessitated a longer period of time eating than allowed by restricted feeder access and free access for normal feeding and social behaviours.

4.2.2. HE

Variables characterized in the study do not facilitate identification of factors responsible for treatment differences in HE. The longer period of time spent eating by Control animals may have contributed to relatively high HE (Osuji 1974; Sahlul et al. 2004). With the general assumption of less efficient use of dietary ME for tissue gain than for milk energy accretion (NRC 2007), greater tissue energy accretion and less milk energy yield for Control compared with restricted feeder access treatments could have contributed to high HE. Relatedly, high ADG and low milk energy yield for the Control relative to other treatments, particularly 4Hour, resulted in a tendency for a correlation between the variables ($r = -0.30$; $P = .062$). In this regard, reasons for high ADG by Control animals are unclear as well. In contrast to findings of the present experiment, ADG did not differ among these treatments in experiment 1 with goats in mid- to late lactation. Though not characterized, treatment influences on hormonal conditions of the Control treatment in the present experiment could have contributed to high ADG. Relatedly, in experiment 1, there were treatment effects on blood concentrations of leptin and IGF-1, but which were not clearly related to treatment effects on ADG or other variables. The tendency for a lower concentration of fat in milk of Control animals might have involved differences in ruminal volatile fatty acids, such as a lower acetate:propionate ration, because of greater feed intake that influenced levels of other hormones like insulin to impact nutrient partitioning.

Another factor worth considering to explain nutrient and energy use for milk yield vs. ADG is the possible influence of treatments on the temporal pattern of nutrient availability in the mammary gland for milk component secretion and synthesis of protein and fat in peripheral tissues. Perhaps steadier and less fluctuating blood metabolite levels over time presumably for the Control treatment may be relatively more important

for peripheral tissue accretion than milk secretion. This also might encompass appreciable capacity of milk storage in the gland cistern between milking times in the morning and afternoon as well as little turnover of milk components once synthesized vs. continual degradation and need for resynthesis of peripheral tissue components, notably protein. However, this implies nutrient partitioning regulated not only by daily quantities of nutrients presented to mammary and peripheral tissues but also temporal patterns, suggestive of likely effects of the ingredient and chemical composition of the diet.

4.2.3. Milk yield and composition

Milk fat concentration was mainly responsible for treatment differences in yield of adjusted milk and energy between both Control and restricted access treatments and 4Hour vs. 2Hour, Day, and Night. Though factors responsible for differences in fat concentration are unknown, high tissue energy accretion by Control animals, presumably with associated nutrient partitioning, conceivably contributed to low milk fat. Although, rationale for hypothesizing one factor as the cause and the other condition the effect is not readily apparent. Alternatively, it is conceivable that in some manner, the Control treatment resulted in a greater quantity of bioactive conjugated linoleic acid isomers reaching the mammary gland to depress *de novo* fatty acid synthesis, the likelihood of which may have been increased by dietary inclusion of soybean oil at 3% (Goetsch 2016). Ruminal pH, as a primary influencer of the rate and completeness of biohydrogenation, was not monitored, but it would be expected that the temporal pattern differed considerably among treatments.

It is unclear why milk fat concentration and, consequently, adjusted milk and energy yields were relatively high among restricted feeder access treatments for 4Hour, other than the possibility of nutrient partitioning resulting from a unique array and temporal pattern of nutrient availability resulting from this treatment. Conversely, in experiment 1 conducted in mid- to late lactation, these variables were low for 4Hour relative to Control and other limited feeder access treatments.

4.2.4. Experimental conditions

This experiment was conducted subsequent to experiment 1 with Alpine goats from 4.1 to 6.9 mo of lactation consuming the same diet and with similar other conditions. An overall conclusion of experiment 1 was that there is considerable flexibility in eating behaviour of lactating dairy goats that prevented appreciable effect of the markedly different lengths and periods of feeder access. Nonetheless, it was qualified that the findings could not necessarily be extrapolated to earlier stages of lactation because of differences in nutrient and energy demands and potential for their usage. Though based on a limited number of significant effects and many tendencies and numerical differences, results of the present experiment do generally support influences of the stage of lactation that should be considered in future research.

Neither this study nor experiment 1 directed attention to likely impacts of the nature of the diet. The diet used in these experiments was formulated to be relatively high in quality so as to allow opportunity for a rapid rate of ingestion and acceptable performance with limited feeder access treatments.

Although this seems appropriate for initial investigations, comparisons of diets differing in total and effective fibre, starch, metabolizable protein, and so on would be of interest in regard to potential impact on total eating time, HE by the gastrointestinal tract relative to energy absorption (Goetsch 1998), and nutrient partitioning.

5. Conclusion

In experiment 1, despite many effects on behaviour by Alpine goats in mid- to late lactation, the restricted feed access treatments had neither marked negative nor positive effects on feed intake and performance measures, reflecting considerable flexibility in feeding behaviour. An exception is reduced adjusted milk yield for the 4Hour treatment, although yield relative to DM intake and ME intake were not impacted. Conversely, with Alpine goats of experiment 2 in early to mid-lactation, continuous feeder access resulted in greater feed intake than for limited access treatments. This was not accompanied by greater milk yield, but was rather associated with high ADG. In addition, feeder access for 2 h after morning and afternoon milking increased milk fat concentration that led to relatively high adjusted milk yield and milk energy without elevating HE. Factors responsible for these effects are unclear but suggest potential to influence level and efficiency of production by lactating dairy goats in early to mid-lactation by varying periods of feeder access. With the somewhat different findings noted in experiment 1, further research is warranted to address an entire lactation period as well as diets differing in ingredient composition and quality.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

The project was supported by the USDA National Institute for Food and Agriculture (NIFA) Evans-Allen Projects OKLXSAHLU2012, accession number 0228824, and OKLUSAHLU2017, accession number 1012650.

References

- Amundson JL, Mader TL, Rasby RJ, Hu QS. 2006. Environmental effects on pregnancy rate in beef cattle. *J Anim Sci.* 84:3415–3420.
- AOAC. 2006. Official methods of analysis, 18th ed. Gaithersburg, MD: AOAC International.
- Berhan T, Puchala R, Goetsch AL, Sahlu T, Merkel RC. 2005. Effects of length of pasture access on energy use by growing meat goats. *J Appl Anim Res.* 28:1–7.
- Brouwer E. 1965. Report of sub-committee on constants and factors. In: Blaxter KL, editor. *Energy metabolism. Proc 3rd Symp European Assoc Anim Prod Publ No. 11.* London: Academic Press; p. 441–4430.
- Delavaud C, Bocquier F, Chilliard Y, Keisler DH, Gertler A, Kann G. 2000. Plasma leptin determination in ruminants: effect of nutritional status and body fatness on plasma leptin concentration assessed by a specific RIA in sheep. *J Endocrinol.* 165:519–526.
- Gipson TA, Goetsch AL, Detweiler G, Merkel RC, Sahlu T. 2006. Effects of the number of yearling Boer crossbred wethers per automated feeding system unit on feed intake, feeding behavior and growth performance. *Small Rumin Res.* 65:161–169.

- Gipson TA, Goetsch AL, Detweiler G, Sahlu T. 2007. Effects of feeding method, diet nutritive value and physical form and genotype on feed intake, feeding behavior and growth performance by meat goats. *Small Rumin Res.* 71:170–178.
- Goetsch AL. 1998. Splanchnic tissue energy use in ruminants that consume forage-based diets ad libitum. *J Anim Sci.* 76:2737–2746.
- Goetsch AL. 2016. Invited review: current areas of research of feeding practices for lactating goats. *Prof Anim Scientist.* 32:25–735.
- Grant R. 2016. New take on how forage fiber affects cow's eating behavior. In: *Feedstuffs*. Bloomington, MN: Penton Agriculture; p. 34–36.
- Keli A, Ribeiro LPS, Gipson TA, Puchala R, Tesfai K, Tsukahara Y, Sahlu T, Goetsch AL. 2017. Effects of pasture access regime on performance, grazing behavior, and energy utilization by Alpine goats in early and mid-lactation. *Small Rumin Res.* 154:58–69.
- Littell RC, Milliken GA, Stroup WW, Wolfinger RD. 1996. SAS® systems for mixed models. Cary (NC): SAS Inst. Inc.
- Morrison CD, Wood R, McFadin EL, Whitley NC, Keisler DH. 2002. Effect of intravenous infusion of recombinant ovine leptin on feed intake and serum concentrations of GH, LH, insulin, IGF-I, cortisol, and thyroxine in growing prepubertal ewe lambs. *Dom Anim Endocrinol.* 22:103–112.
- Ngwa AT, Dawson LJ, Puchala R, Detweiler G, Merkel RC, Tovar-Luna I, Sahlu T, Ferrell CL, Goetsch AL. 2007. Urea space and body condition score to predict body composition of meat goats. *Small Rumin Res.* 73:27–36.
- NRC. 1984. Nutrient requirements of beef cattle, 6th rev. ed. Washington (DC): National Academy Press.
- NRC. 2001. Nutrient requirements of dairy cattle. 7th rev. ed. Washington (DC): National Academy Press.
- NRC. 2007. Nutrient requirements of small ruminants. Sheep, goats, cervids, and new world camelids. Washington (DC): National Academy Press.
- Osuji PO. 1974. The physiology of eating and the energy expenditure of the ruminant at pasture. *J Range Manage.* 27:437–443.
- Patra AK, Puchala R, Animut G, Gipson TA, Sahlu T, Goetsch AL. 2009. Effects of acclimatization on energy expenditure by meat goats. *Small Rumin Res.* 81:42–54.
- Patra AK, Puchala R, Detweiler G, Dawson LJ, Animut G, Sahlu T, Goetsch AL. 2008a. Effects of tethering on forage selection, intake, and digestibility, grazing behavior, and energy expenditure by Boer × Spanish goats grazing high quality forage. *J Anim Sci.* 86:1245–1253.
- Patra AK, Puchala R, Detweiler G, Dawson LJ, Sahlu T, Goetsch AL. 2008b. Tethering meat goats grazing forage of high nutritive value and low to moderate mass. *Asian-Australas. J Anim Sci.* 21:1252–1261.
- Powell MR, Keisler DH. 1995. A potential strategy for decreasing milk production in the ewe at weaning using a growth hormone release blocker. *J Anim Sci.* 73:1901–1905.
- Preston RL. 2015. 2015 feed composition table. In *Beef Magazine* 51 (7). New York (NY): Penton; p. 14–29.
- Puchala R, Tovar-Luna I, Goetsch A, Sahlu T, Carstens GE, Freely HC. 2007. The relationship between heart rate and energy expenditure in Alpine, Angora, Boer and Spanish goat wethers goats consuming different quality diets at level of intake near maintenance or fasting. *Small Rumin Res.* 70:183–193.
- Puchala R, Tovar-Luna I, Sahlu T, Freely HC, Goetsch AL. 2009. The relationship between heart rate and energy expenditure in growing crossbred Boer and Spanish wethers. *J Anim Sci.* 87:1714–1721.
- Sahlu T, Goetsch AL, Luo J, Nsahlai IV, Moore JE, Galyean ML, Owens FN, Ferrell CL, Johnson ZB. 2004. Nutrient requirements of goats: Developed equations, other considerations, and future research to improve them. *Small Rumin Res.* 53:191–219.
- SAS. 2011. SAS/STAT® 9.3 user's guide. Cary (NC): SAS Inst. Inc.
- Silanikove N, Koluman N. 2015. Impact of climate change on the dairy industry in temperate zones: predictions on the overall negative impact and on the positive role of dairy goats in adaptation to earth warming. *Small Ruminant Research.* 123:27–34.
- Tovar-Luna I, Puchala R, Gipson TA, Detweiler GD, Dawson LJ, Keli A, Goetsch AL. 2011. Effects of night-locking and stage of production on forage intake, digestion, behavior, and energy utilization by meat goat does grazing grass/legume pasture. *Livest Sci.* 40:225–245.
- Tsukahara Y, Gipson TA, Sahlu T, Puchala R, Goetsch AL. 2014. Effects of the number of animals per pen and length and time of automated feeder access on feed intake, growth performance, and behavior of yearling Boer wethers. *Small Rumin Res.* 121:289–299.