Livestock Science 263 (2022) 104982

Contents lists available at ScienceDirect

Livestock Science

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

Review article

A review on the effects of part-time grazing herbaceous pastures on feeding behaviour and intake of cattle, sheep and horses

Giovanni Molle[a,*], Antonello Cannas[b], Pablo Gregorini[c]

[a] Agris Sardegna, loc. Bonassai 07040 Olmedo (Sassari), Italy
[b] Dipartimento di Agraria, Università di Sassari, 07100 Sassari, Italy
[c] Department of Agricultural Sciences, Lincoln University, Lincoln, 7647, New Zealand

HIGHLIGHTS

- Part-time grazing (PTG) ruminants display compensatory ingestive behaviour
- They achieve levels of performance as good as 24 h-grazing ruminants if AT is 6-8 h/d.
- PTG can results in reduction of energy expenditure and selective behaviour but fibre digestibility could be constrained
- Beneficial FA in milk is usually higher in PTG than stall-fed ruminants
- Horses show lower intake rates scaled to metabolic weight than ruminants
- Horses are less adapted to short access time to pasture

ARTICLE INFO

Keywords:
time-restricted feeding
herbivores
milk
meat
energy expenditure

ABSTRACT

Part-time grazing (PTG) is the grazing technique based on the time-restricted access to pasture of farmed herbivores, usually supplemented indoors. This review evaluates the effects of the duration of access to pasture on the functional responses of grazing time and herbage intake rate in cattle, sheep and horses and the implications of these responses on diet selection, diet digestibility, energy expenditure, animal welfare, the performance of ruminants and the quality of their products (milk and meat).

Ruminants with restricted access time to pasture display compensatory behaviour through increased intake rate, achieving similar levels of intake and performance compared with 24 h-grazing ruminants, particularly if access time is in the range 6-8 h/d. This can depend on the reduction of locomotion energy expenditure, and, sometimes, on the selection of a better quality diet than that on offer. Nevertheless, due to lower ingestive fibre trituration, fibre digestibility could be reduced, particularly with access time <4 h/d. Moreover, milk content of FA regarded as beneficial for consumers'health, such as n-3 PUFA and rumenic acid, is usually higher in PTG than stall-fed ruminants, with a minimum access to grass pasture of 6 h/d in cows supplemented with total mixed rations or 4 h/d in sheep supplemented with concentrate and hay. Timing the grazing session of ruminants in the afternoon and evening hours is a good strategy to match pasture quality and animal attitude to forage intensively and efficiently, favouring intake, performance and produce quality.

Horses show on average lower intake rates scaled to metabolic weight than ruminants, probably due to their lower energy requirements but also for the need to spend part of the time outdoor performing physical activity and social behavior. Therefore, they probably need longer access time than ruminants. However, access should be time restricted or avoided during periods of the year and day hours (from midday to evening) when herbage content of non structural carbohydrates (sum of starch and water soluble carbohydrates) is high (> 15 % DM) since it can be conducive to equine metabolic syndrome and laminitis.

In general, PTG can improve ruminant and horse welfare as compared with stall-feeding with reference to appropriate behavior and freedom from some pathologies, although further research is needed to quantify these effects on a wider range of animal species and welfare indicators.

* Corresponding author.
E-mail address: gmolle@agrisricerca.it (G. Molle).

https://doi.org/10.1016/j.livsci.2022.104982
Received 31 May 2021; Received in revised form 25 May 2022; Accepted 26 May 2022
Available online 18 June 2022

To conclude, PTG in ruminants and horse offers some benefits when properly managed, compared to 24 h-grazing and stall-feeding.

1. Introduction

In the last two decades several researchers have investigated the pros and cons of grazing of ruminants (e.g. Bellarby et al., 2013; Gregorini et al., 2017) and horses (Bott et al., 2013) as compared to confinement feeding. Benefits include lower feeding costs (Shalloo et al., 2004), lower carbon footprint (Dall-Orsoletta et al., 2016) and better animal health and well-being (Provenza et al., 2015), provided herbivores are sheltered from extreme weather conditions and adequately supplemented with concentrates and conserved forages (Molle et al., 2008, Knowles and Grace, 2013). Furthermore, grazing provides ecosystem services, such as conservation of biodiversity, and protection of soil and water resources of utmost importance at local and global levels. Finally, 'grass-fed' dairy and meat products are often featured by high contents of micro-nutrients, such as polyunsaturated fatty acids (PUFA), known to enhance the "nutraceutical value" of products (Dewhurst et al., 2006; Buccioni et al., 2012; Provenza et al., 2019). However, grazing herbivores are more exposed to harsh climatic conditions, toxic plants, fluctuating feed quality and to a vast array of ecto and endoparasites than stall-fed herbivores.

Restricting the access time to pasture, i.e. adopting a part-time grazing (PTG) technique, can be a good compromise, providing some advantages as compared with 24 h-grazing. They include: i) reduced sward damages due to less animal trampling, treading and fouling (e.g. Bott et al., 2013); ii) increased rate and evenness of herbage utilization due to less pasture contamination (Gregorini, 2012); iii) increased nitrogen utilization (Clark et al., 2010; Santana et al., 2017); iv) less risk of predation particularly in small ruminant grazing at night.

In contrast, some of the putative disadvantages of PTG as compared 24 h-grazing are: i) a lower quality of products (with reference to beneficial PUFA and other plant-sourced micro-nutrients (Dewhurst et al., 2012; Buccioni et al., 2012); ii) a lower level of ecosystem service provision; iii) higher labour input related to animal husbandry in non milked herbivores; iv) lower ability of animals to select and limit the intake of plants species or parts of plants with low nutritive value; v) need to use larger amounts of supplements, likely increasing the cost of the diet and the external nutrient inputs.

The access time to pasture could affect differently feeding behaviour, intake and digestion in large ruminants, small ruminants and non-ruminant herbivores, such as the horse, whose gastro-intestinal tract, requirements and behavioural pattern are well differentiated.

Rumen capacity is much higher in cows than sheep per unit of energy requirements (e.g. Cannas, 2004) and sheep have much higher DM intake (Van Soest, 1994) and NDF intake (Cannas et al., 2016), as proportion of liveweight, and are more selective than cattle (Van Soest, 1994). Horses, due to their monogastric digestive system, need to split their foraging in many meals during the daytime but, thanks to their large and highly compartmentalized hindgut where fibre is fermented, can utilize coarse diets (Van Soest, 1994), and increase to some extent their intake with increasing dietary fiber, differently from ruminants (Eduard et al., 2008). Moreover, they have usually shorter transit time and lower digestibility of fiber than ruminants, particularly at low levels of intake (Clauss, 2013). Grazing, i.e. foraging behaviour at pasture, hereunder considered as "area of sward canopy enclosed by fences", is affected, among other factors, by the perception of the predation risk by the herbivore (Bakker et al., 2005, Laporte et al., 2010). Ruminants, particularly if hornless, have limited escape and defensive ability towards predators. Horses, the fastest domesticated herbivores, can extend their foraging to the dark hours, when predation risk is higher. On the other hand, horses have to do so (i.e. foraging for a long time at a slow rate) to compensate for the limited storing capacity of their monogastric digestive system. Therefore, it seems reasonable to expect that cow, sheep and horse can respond differently to PTG.

This review primarily aims at highlighting the impact of PTG on feeding behaviour and intake of grazing ruminants and the functional responses to changes in duration of daily grazing sessions. A side-objective is the assessment of the difference in the response to PTG among animal species, with particular reference to cattle, sheep and horses.

In the following sections, we will sequentially review:

1) the literature concerning the biological mechanism underlying the effect of time on foraging in grazing animals (overviewed in Section 2);
2) the effects of access time (AT, h/d) to pasture of ruminants and horses on:
   a feeding behaviour (Section 3), inclusive of grazing time (3.1), herbage intake rate (3.2) and their integrated response (herbage intake) (3.3);
   b diet selection and digestibility (Section 4);
   c energy expenditure (Section 5);
   d ruminant performance (direct and indirect effects) (Section 6);
   e animal welfare (Section 7).

Finally, the main take-home messages and and future research needs will be presented (Section 8).

For the purpose of this study, scientific literature was explored by using keywords such as grazing AND ruminants OR horses in bibliographic databases. Only papers where at least one grazing treatment was time restricted were selected for further analysis.

Although this review is conceptual in nature, the herbage intake rate response to different AT by cattle, sheep and horse was submitted to a modelling exercise with the aim to quantify the differences between these herbivore species. To this end, papers were filtered using keywords such as grazing & intake or pasture & intake, for the different animal species. No time span restriction was implemented. Then, selected papers were screened using as main inclusive criteria: 1) publication in peer refereed journals, 2) explicit focus on the effect of AT on herbage intake rate; 3) pasture based on grass, (i.e. excluding data referred to the grazing of legumes or forbs).

2. Tenets of the effect of time on foraging

In wild and free-ranging domesticated herbivores, foraging follows a well described pattern (Arnold and Dudzinsky, 1978). This pattern has a circadian cycle because of the powerful influence of light-dark cycle. However, it often includes an ultradian rhythm of ingestive activities of 4-6h, depending on animal species and length of digesta retention time. In ruminants, the main meals and the main rumination periods are concentrated in the day-time and night-time, respectively (**Fig. 1a**). Besides the extreme latitudes of the Poles, in all seasons, the beginning of the first grazing meal of ruminants is usually synchronized with the time of dawn.

Light stimulus is sensed by specialized retinal photoreceptors and conveyed to the hypothalamic suprachiasmatic nucleus (Meijr and Rietveld, 1989). This is the master pacemaker of feeding activity, due its cross-talk with the hunger and satiety centres of hypothalamus in the central nervous system (Freedman et al., 1999). The pace depends on 'clock genes', which originate transcriptional/translational feedback loops able to synchronise the hypothalamic suprachiasmatic nucleus to the 24 h almost exactly (Ko and Takahashi, 2006). Hence, due to the wide neural network centred in the light-driven pacemaker, undisturbed ruminants tend to start grazing at sunrise and stop grazing during dark hours, although nocturnal grazing has been reported in cows grazing in summer and hot weather conditions (e.g. Hassoun, 2002). Horses show a feeding behaviour pattern with ultradian peaks at pasture spread throughout over the 24 h, possibly as a result of a weaker photic entrainment in horse than in ruminant species (Murphy, 2019).

In farmed animals, natural grazing patterns is artificially broken and or modulated into more discrete meals (arrangements of ingestive bouts), due to handling procedures such as milking in dairy animals, supplements offer, corralling to prevent predation (**Fig. 1b**).

If the feed (pasture) offer is repeated daily at the same time this meal usually becomes a "zeitgeber" (time-maker), promoting the activity of another oscillator, named 'food-entrainable oscillator' (FEO) (Mistleberger, 2004). This 'metabolic clock' is the pacemaker able to elicit a circadian rythm, called 'food anticipatory activity', which includes a simultaneous raise of locomotor activity, body temperature and plasma cortisol or corticosterone concentration just before the timed meal. The FEO could be located in different peripheral tissues and organs (Stokkan et al., 2001). In other words, there could be a web of interacting FEOs rather one single FEO, regulated by clock'genes, likewise the light entrainable oscillator (Feillet et al., 2006).

Under free-ranging conditions, FEO and light entrainable oscillator are usually coupled (synchronous) but feeding management can discontinue this natural synchronization, e.g. when access to pasture is time restricted and delayed repeatedly and regularly towards midday or evening hours. In this case, as demonstrated in rodents, FEO can temporarily 'overtake' the light entrainable oscillator (Herzog and Muglia, 2006). Under these circumstances, time-bound access to feed:

i) can be perceived and memorized by the animals due FEO's web and related hormonal cascade, resulting in a reward expectation (Grieveldinger et al., 2011);
ii) this, in its turn, can bring food anticipatory activity with increasing intensity along with a) the increased asynchrony (phase angles); b) the shortening of time access to feed; and c) the hunger level (Misterberger, 2004; Piccione et al., 2003).

Therefore, herbivores submitted to a routinary PTG regime can to some extent foresee the time of pasture allocation and this can contribute to "boost" their feeding behavioural response.

3. Effect of AT on feeding behaviour

In the following sections, the effects of PTG in terms of severity (constraint of AT in PTG herbivores, measured as h/day) and duration (length of PTG method application, measured as days) will be examined, considering several facets of herbivores' ingestive behaviour.

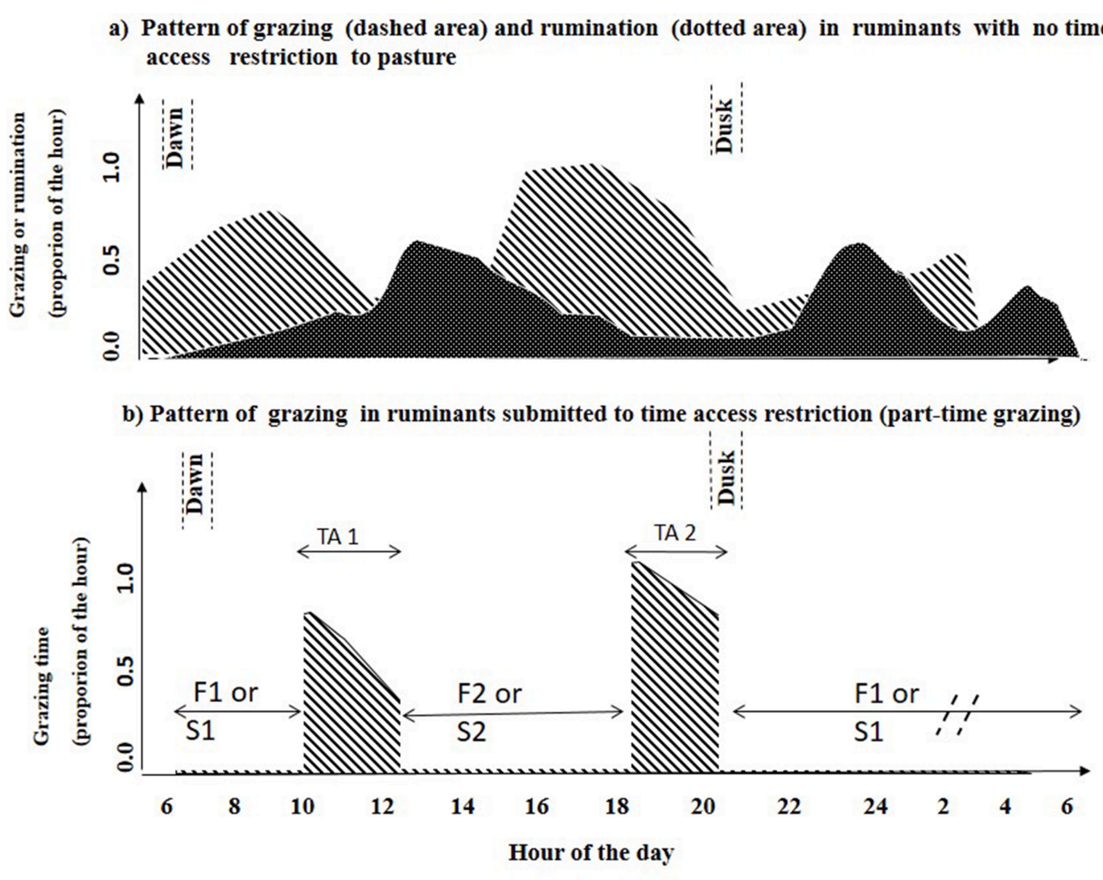

Fig. 1. A schematic description of the pattern of feeding behaviour at pasture in ruminants without (a) or with restriction of access time to pasture (b). In non-restricted time access conditions (a), grazing time is usually concentrated in two or three main grazing bouts at dawn, afternoon and evening, before dusk. When time at pasture is restricted (b) grazing usually becomes the main or the only activity at pasture. The time complement to 24 hours can be either devoted to fasting (F) or available for eating supplements (S). In both cases the time complement is also partially available for drinking, rumination, idling and social interaction.
The time restriction can be measured as total time access, i.e. the sum of the daily time allocations to pasture (TA1 + TA2 in the example). The timing of access to pasture is indicated by the actual clock time of entry to and exit from pasture (10:00-12:00 and 18:00-20:00, in the example). Finally, frequency of allocation is the number of grazing sessions in a day (2, in the example).

3.1. Grazing time

Grazing time (GT) is the time the herbivores devote to search and ingest herbage at pasture thus affecting daily herbage intake (Allden and Whittaker, 1970; Penning, 1986) as presented below, mechanistically:

$$HDMI = GT \times HDMIR \quad (1)$$

where:
HDMI herbage DM intake (g DM/d);
GT grazing time (min of grazing/d);
HDMIR herbage DM intake rate (g DM/ min of grazing).

In this general equation, grazing time GT is the measured free expression of animal feeding behaviour at pasture. In contrast, in the case of PTG, GT does not depend only on the animal behaviour. In fact, under PTG, GT can be partitioned in two factors, depending on management (AT) and on animal behaviour (GTP). The derived equation is as follows:

$$HDMI = AT \times GTP \times HDMIR \quad (2)$$

Where:
AT access time to pasture (min/d);
GTP grazing time as proportion of AT.

The equation 2 suggests that under PTG, herbage intake is affected by AT, *in primis* through a putative reduction of GT. In theory, the constraining effect of AT can be nil, when GT under unrestrained conditions is lower than AT (GT in equation 1 <<AT). For instance, this occurs in non-lactating ruminants accessing pasture for 7-8 h/d with sufficient herbage availability and accessibility. In contrast, if the stop of grazing in PTG occurs well before the natural break, due to surfeit or satiety (GT>>AT), this can result in a lower HDMI, unless a raise of GTP and HDMIR compensate for the short AT.

Due to the anatomical and physiological differences previously reported, the effects of the restriction of AT will be discussed separately for each species.

3.1.1. Cattle

In most of PTG studies with dairy cattle, GT decreases with AT while the GTP increases linearly or exponentially, depending on the study (**Fig. 2a**). Similar responses have been reported for beef cattle (Felix et al., 2017). A previous review (Chilibroste et al., 2015) found a similar relationship in cattle submitted to PTG, with slope coefficient (0.927) exponential power (0.037) and R^2 (0.79), slightly lower than in our case. Our review and that of Chilibroste et al. (2015) concur to evidence a compensatory mechanism, where cattle respond to a reduced AT to

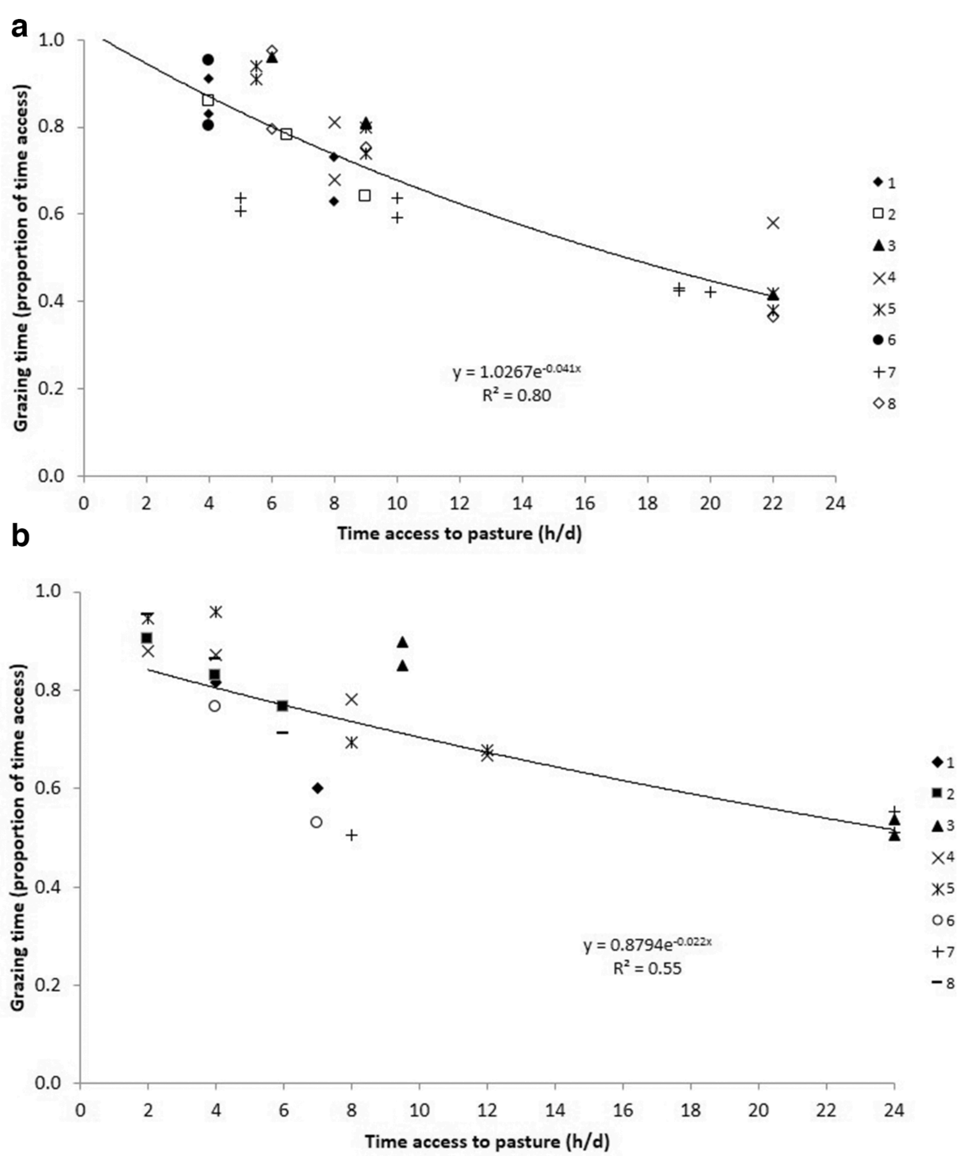

Fig. 2. Grazing proportion of access time in part-time grazing cows (a) and sheep (b). Data on cattle (2a) refer to: 1, Perez-Ramirez et al., 2008; 2, Kristensen et al., 2007; 3, Kennedy et al., 2009; 4, Gregorini et al., 2009b; 5, Perez-Ramirez et al., 2009; 6, Mattiauda et al., 2013; 7, Hernandez-Mendo and Leaver 2004; 8, Kennedy et al., 2011; 9, Delaby et al., 2008; 10, Rego et al., 2008; 11, Dillon et al., 2002. Data on sheep (2b) refer to 1, Garcia-Rodriguez et al., 2005; 2, Molle et al., 2014; 3, Iason et al., 1999; 4, Chen et al., 2013; 5, Zhang et al., 2014; 6, Perojo et al., 2005; 7, Alvarez-Rodriguez et al., 2007; 8, Molle et al., 2017; 9, De Renobales et al., 2012; 10, Cabiddu et al., 2017; 11, Valenti et al., 2017; 12, Garcia-Rodriguez and Oregui, 2004.

pasture by re-allocating their time budget in favour of foraging. The plasticity of GT is a measure of adaptation capability of free-ranging herbivores to tackle the continuous changes of weather, resource availability and predation risks that they experience in grazing systems.

Grazing time is also affected by the level and quality of supplementation. As reported in numerous studies (Bargo et al., 2003; Tedeschi et al., 2019), the greater the level of supplementation the lower the GT. This occurs also in cows submitted to PTG, as reported by Perez–Ramirez et al. (2008). This reduction of GT is caused by a post-ingestive negative feedback loop. Cereal grains and starch-based concentrates at high supplementation level can also depress GT, due to a possible impairment of rumen function [sub-clinical or clinical acidosis, (e.g. Bargo et al., 2003)].

The pattern and duration of grazing in ruminants subjected to PTG is also affected by rumen fill. According to Taweel et al. (2006), rumen fill affects more the termination of the meal preceding dusk (evening meal) than of those following dawn (morning meal) or midday (afternoon meal). Gregorini et al. (2007) highlighted the role of rumen fill in controlling the feeding behaviour, by decreasing total eating time, intake rate, and bites per feeding station but increasing searching time and bite depth.

Several studies have investigated the influence of AT restriction on the number of bouts, which usually decrease, and meal duration, which, in contrast, increases (Perez-Ramirez, et al., 2008; Kennedy et al., 2009; Gregorini et al., 2011). The restriction of AT decreased the number of feeding stations per grazing session, whereas the number of bites per feeding station increased (Gregorini et al., 2011). These reports demonstrate the change of focus of the animal to foraging rather than walking and searching for alternate resources.

Foraging is usually synchronous among herd or flock mates (Penning et al., 1993). Herbivores grazing on the same plot tend to start grazing all together at certain clock hours, if free ranging, or shortly after pasture is allocated, if under PTG. However, they usually stop grazing at different times, according to their different requirements and or hunger levels. For example, lactating cows have longer grazing times than non-lactating counterparts (Gibb et al., 1999). Therefore, in severely AT restricted ruminants, the time constraint could affect proportionally more high-yielding than low-yielding ruminants. However, to the best of our knowledge, direct and explicit delving into this aspect with reference to PTG ruminants has not been reported so far. Gregorini et al. (2015) found that dairy cows selected for low residual feed intake showed a longer GT in the first meal as compared with cows selected for high residual feed intake, postponing rumination later in the day.

Another aspect that deserves further investigation is the the effect of the size of grazing herd as modulator of grazing time. Group grazing ensures that the experience accumulated by each animal is shared among all (in goats: Shrader et al., 2007, Landau and Provenza, 2020) but increasing the group size can enhance the inter-individual competition for feed and may decrease the average intake, through an increase of walking vs grazing time, and a lower intake rate.

Rumination time has a fundamental impact on ingestive process. Trituration of particles plays a fundamental role in favouring their degradation by rumen microbes and transit through the gastro-intestinal tract. Rumination time is usually shorter during 'short' AT, with the animal postponing rumination to periods in which they have no access to pasture (e.g. Perez-Ramirez et al., 2008).

The pattern of rumination is also important. Gregorini et al. (2012b), showed that cows allocated to pasture once daily for 8 h had a lower rumination time than cows with c.a. 22 h/d AT, with a much lower rumination activity during the night. Splitting the AT in two grazing sessions of 4 h each alleviated the effect of the constrained allocation on rumination time. In general, the reduction of rumination time can slow down the rate of fiber fermentation in the rumen (Beauchemin, 2018).

3.1.2. Sheep and goats

Grazing time and eating time have been proven to be sensitive to the shortening of AT. For instance, an increase in GTP was observed in continuously stocked lactating meat sheep submitted to a moderate time restriction [(9.5 vs. 24 h/d, (Iason et al., 1999)] or to a more severe AT restriction (2, 4 and 6 h/d) in dairy sheep rotationally grazing Italian ryegrass (Molle et al., 2014a) or berseem clover (Molle et al., 2017). The functional response to access time of sheep is depicted in **Fig. 2b**.

In sheep, like in cattle, rumination time and idling times at pasture decrease with short AT, as found in dairy ewes submitted to a severe restriction of AT (2 h/d) to Italian ryegrass (Molle et al., 2014a) or berseem clover (Molle et al., 2017). Unfortunately, in these studies, the authors were unable to measure the total time devoted daily to each activity, so a compensation effect during housing cannot be ruled out. Goats grazing grass pastures seem to behave like sheep, the shorter the AT is, the greater the GTP (Keli et al., 2017; Charpentier and Delagarde, 2018; Charpentier and Delagarde, 2019).

3.1.3. Horse

Taking for granted the compensatory behaviour already shown in ruminants, the raise of GTP in horse with restricted AT can be expected. As reviewed by Ellis (2010) grazing meals are often shorter and more numerous in horses than ruminants, which could be easily explained by the limited reservoir volume (the stomach) in their gastro-intestinal tract. Therefore, horses could respond to restricted AT with smaller increase in GTP, as compared to ruminants. However, to the best of our knowledge, data is lacking to test this hypothesis.

3.2. Herbage intake rate

The functional response to AT in the herbivore operates at the level of intake rate components, namely bite rate (BR, n. bites/min) and bite mass (BM, g DM).

Bite rate increases with the reduction of AT (Table 1). The time devoted to bite is relatively constant [0.68 s, in cattle (Laca et al., 1994)], whereas the time devoted to orally processing the ingestive bolus before swallowing is variable (Ungar, 1996). So PTG herbivores tend to reduce mastication in favour of biting, as shown in cattle by the raise of the bite to chew ratio (Kennedy et al., 2009). This effect depends also on forage characteristics: short but dense swards in general favour the increase of BR as compared with tall and sparse swards (Ungar, 1996).

Bite mass increases with the reduction of AT or the increase in fasting duration (Table 1). Bite mass is probably the most sensitive driver of herbage intake. In grazing conditions, BM depends on sward and animal factors. Herbage bulk density is the most relevant herbage modulator of BM (Ungar, 1996): it changes with forage species, grazing management and within species and grazing methods, across swards canopy strata and daytime. In other words, many pasture variables can explain the increase of BM in herbivores facing a short AT. From the animal point of view, if all pasture drivers remain equal, BM can change through an increase of bite depth or bite area. In dairy cattle, the latter has been found to increase with reduction of rumen fill (Gregorini et al., 2007; Gregorini et al., 2009a).

3.2.1. Cattle

Taking into account the effects of PTG on the above components of the herbage intake rate, it is not surprising that HDMIR increases when cattle are submitted to severe decrease of AT (**Fig. 3a**). In fact, intake rate is the product of BM by BR, both of which usually increase as AT is shortened. Herbage intake rate varies with hunger level (e.g. affected by supplementation regimen), with usually higher HDMIR in cows fed no supplements than in counterparts fed supplements (Perez-Ramirez, et al., 2008), and a trend to higher values in time-restricted cows grazing at low than high herbage allowance (Perez-Ramirez, et al., 2009). Thus, as cattle perceive reductions in AT, they compensate for it by eating faster. This trend is exponential (Fig. 3a), showing a time threshold below which the increase is more relevant. This trend also suggest that

Table 1

Effects of restriction of time access to pasture on bite mass (BM) and bite rate (BR) in part-time grazing ruminants.

Reference	Animal type	DIM days	IBW kg	IMY kg/d	Exper. period	Pasture type	Grazing method	HM t DM/ha	SH mm	AT h/d	FA n/d	TIMING		BM g DM	BR n/min
Kristensen et al., 2007	Dairy cows	96	592	31	Growing season (6 wks)	Perennial ryegrass + clover	Cont. stocking	1.8	115	4	1	06:30	10:30	0.866	57
								1.6	110	6.5	1	06:30	13:00	0.625	59
								1.5	103	9	1	06:30	15:30	0.622	58
Kennedy et al. 2009	Dairy cows	202	591	24	Mar-Apr	Perennial ryegrass 80%	Strip grazing	1.3	64	6	2	§	§	0.690	56
								1.2	62	9	1	§	§	0.480	58
								1.3	63	9	2	§	§	0.520	59
								1.2	61	22	2	§	§	0.470	57
Gregorini et al., 2009b	Dairy cows	35	470	24	Sept-Oct	Mostly Perennial ryegrass	Strip grazing	3.2*		8	1	08:00	16:00	1.99*	55*
								3.3*		8	2	08:00	16:00	1.98*	57*
								3.3*		22	2	08:00	06:00	1.42*	49*
Mattiauda et al., 2013	Dairy cows	60	550	25	May-July	Mixed grass and legume	Strip grazing	1.5	65	8	1	07:00	15:00		
								1.7	70	4	1	07:00	11:00	0.594	52
								1.5	65	4	1	11:00	15:00	0.709	50
Iason et al., 1999	Lactating meat ewes		54	-	May-Jun	Perennial ryegrass	Contin. stocking		30	9.5	1	09:30	18:30	0.030	72
									50	9.5	1	09:30	18:30	0.038	70
									30	24	1			0.024	69
									50	24	1			0.028	66
Molle et al., 2017	Lactating dairy ewes		42	1.95	Mar-May	Berseem clover	Rotation. grazing	2.2	200	2	1	08:00	10:00	0.250	42
								2.2	190	4	1	08:00	12:00	0.233	36
								2.1	190	6	1	08:00	14:00	0.173	37
Zhang et al., 2014	Lambs		22		Jul-Sept	Steppe	Set stocking			2	1	06:00	08:00	0.109	50
										4	1	06:00	10:00	0.070	51
										8	1	06:00	14:00	0.065	48

Legend: DIM = days in milk; IBW = initial body weight; IMY = initial MY; HM = herbage mass; SH = sward height; AT = access time to pasture; FA = daily frequency of pasture allocation. § timing were approximately 3 and 4.5 h from morning and afternoon milking in treatments 6 (FA = 2) and 9 (FA = 2), respectively and between morning and afternoon milking in treatment 9 (FA =1). In the 22 TA cows were at pasture all day except for the milkings; * initial herbage mass and BM and BR measured in the first 60 minutes of the first daily grazing session.

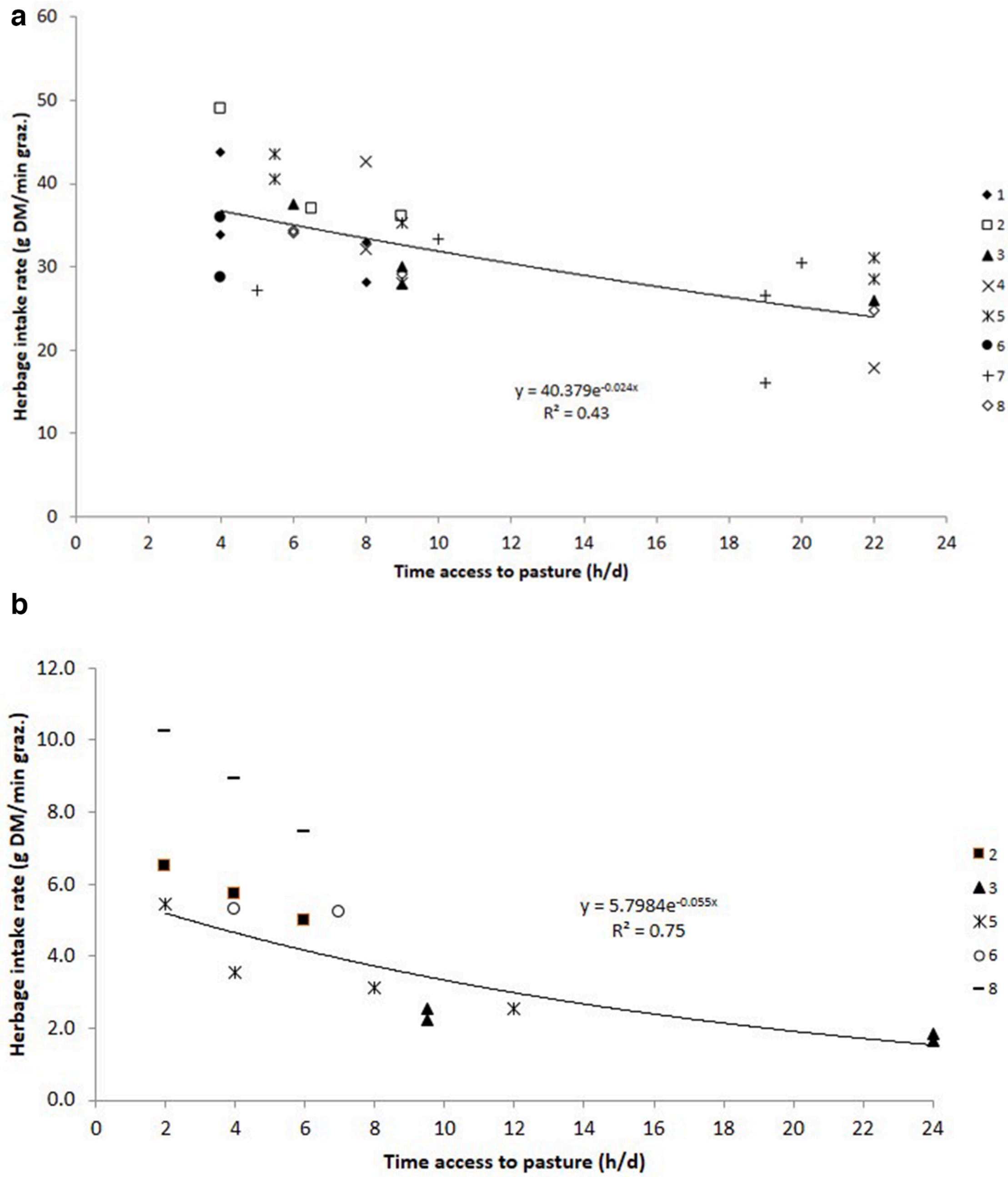

Fig. 3. Herbage intake rate in dairy cows (a) and sheep (b) submitted to part-time grazing. See legend of Fig. 2 for details on data source.

below a certain daily time allocation, some physiological mechanism starts to operate, acting even at a pre-meal level, as shown by the rise of plasma ghrelin concentration in cows devoid of their rumen content (Gregorini et al., 2009b).

Fasting is in fact among the most important booster of HDMIR, as reviewed by Chilibroste et al. (2007). Usually, the longer the fasting, the more acute the response to restrictions in AT. However, only few experiments have disentangled the main effect of fasting from its interaction with the AT restriction. Very often, the effect of fasting, although evident at the beginning of the meal, gradually fades away [transient effect, (Erhard et al., 2001)], whereas AT restriction usually has a long-lasting effects (see carry-over effects in section 6.2).

3.2.2. Sheep and goats

Sheep data support the above presented changes in grazing pattern of cattle under PTG (**Fig. 3b**). Intake rates as high as 10 g DM/min grazing have been measured under extremely time-restricted conditions in dairy sheep grazing a legume monoculture (berseem clover) with AT of 2 h/d (Molle et al., 2017). Also the forage quality can impinge on this variable. In lactating rotationally grazed meat sheep (Orr et al., 1997) and dairy sheep submitted also to PTG (Molle et al., 2014a; Molle et al., 2017), HDMIR was greater on legumes than grass at equal AT. It was also greater in berseem clover than a binary mixture of berseem clover and Italian ryegrass, in the first three hours of AT in milked sheep allocated to pasture for 6 h/d (Molle et al., 2018). Some works report similar patterns of HDMIR response to AT changes in dairy goats (Keli et al., 2017; Charpentier and Delagarde, 2018). Despite sharing the same breed under study (Alpine goats) the intake per hour of AT was almost double in Charpentier and Delagarde (2019) as compared with Keli et al. (2017) due to higher pasture quality and milk production.

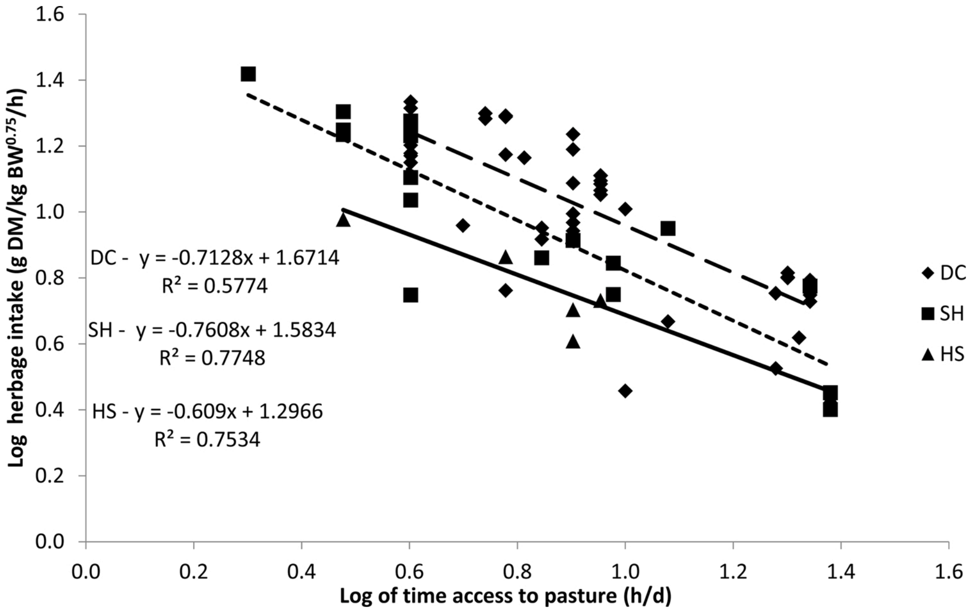

Fig. 4. Regression of log transformed herbage intake rate (expressed as g DM/ kg $BW^{0.75}$ per h access time) upon log transformed access time to pasture (h/day) in part-time grazing dairy cows (DC, dashed line, N = 40), sheep (SH, dotted line, N = 17), and horses (HS, continuous line, N = 7). P-values: species, P <0.02; logAT, P <0.001; species x logAT, P > 0.10. Data source:
Cattle: Delaby et al., 2008; Gregorini et al., 2009b; Hernandez-Mendo and Leaver, 2004; Kennedy et al., 2009; Kennedy et al., 2011; Kristensen et al., 2007; Mattiauda et al., 2013; Perez-Ramirez et al., 2008; Perez-Ramirez et al., 2009; Rego et al., 2008; Sairanen et al., 2006. Sheep: De Renobales et al., 2012; Cabiddu et al., 2017; Iason et al., 1999; Perojo et al., 2005; Zhang et al., 2014. Horse: Dowler et al., 2012; Glunk et al., 2013.

3.2.3. *Horse*

Like ruminants, horses are able to increase HDMIR when AT is restricted (Dowler and Siciliano, 2009; Glunk and Siciliano, 2011). On occasion, their voracity can be high, because they can ingest the herbage needed to cover more than half of their maintenance requirements in the first 4 h of grazing after an overnight fasting (Dowler and Siciliano, 2009). Horses may graze during the night for a high proportion of time, as found in semi-feral Camargue horses (from 49 to 55% of night hours) by Mayes and Duncan (1986). Therefore, we can expect than night fasting can have a higher boosting effect on HDMIR in this species as compared with ruminants. In general, the response to fasting is more relevant in horse than ruminants due to the role of rumen as pre-gastric nutrient reservoir. This is also demonstrated by the stereotypic behaviours that horse display when their meals are unfrequent or delayed (McGreevy et al., 1995), or if the dietary forage contribution in addition to complementary feedstuffs is below recommendation (≤ 15 g/kg BW) (Harris et al., 2017).

3.2.4. *Differences in intake rate between the three species*

The data for comparing HDMIR response in these animal species sourced in N= 11 papers on cattle (N =40 treatment means), N= 5 papers on sheep (N = 17 treatment means), and N = 2 papers on horses (N= 7 treatment means). The modelling exercise was run by regression analysis using SAS, according to Riaz et al. (2014). Firstly, data on intake rate were scaled to metabolic weight (MW, i.e. $BW^{0.75}$). Previous literature results showed that maximum intake rate scales with $BW^{0.71}$, in a range of mammals going from lemmings (0.05 kg) to cattle (547 kg) (Shipley et al., 1994), but this study did not refer to animals submitted to PTG.

Comparing dairy cows, sheep and horses for their hourly intake rate ($HDMIh_{mw,}$ expressed as g DM/ kg of MW per hour of AT), we found that the relationship between the two variables fits an exponential curve for all the species under study. After log-transformation of the variables to linearize the pattern, we found that the intercepts were different among the three species (P < 0.02, among animal species, **Fig. 4**), while the slopes were not. This means that the increase of intake per hour of AT reduction was similar among species, even though, based on the intercept, the intake per kg of MW ranked as follows: cattle > sheep > horse. This result may be a combined effect of the different selectivity (e.g. cattle select less than sheep and thus can eat faster) and of the different daily requirements of the animals, since all dairy cattle studies and about half the sheep were on animal in lactation, while the rest of sheep data and those on horses where not.

Other reasons can explain the generally slower intake rate of horses. In fact, horses invest more chewing per gram of feed relative to body size (kg) than ruminants (Shipley et al., 1994). A higher ingestive particle comminutation can partially offset their lower digestive capacity. Moreover, horses tend to have a higher share than ruminants of time budget devoted to non-feeding behaviours while outdoor. This trend in leisure horse can be explained by their individual housing while stabled, hence a higher need of performing social behaviour. According to Dawkins (1990) the concept of suffering embraces an array of aversive states (fear, pain, frustration) that are experienced by the individual animal. In general, horses seem to suffer i) when diet or management force them to eat fast (e.g. < 10 min/kg, Ellis et al., 2005); ii) when they are fed low amount of forage (e.g. < 15 g/kg BW of daily forage intake in addition to complementary concentrate, Harris et al., 2017; or low amount of chaff in cereal-based meals (<30 % of chaff, Harris, 2007, Campbell et al., 2020), which can result in digestive and metabolic problems and oral stereotypies; or iii) when the forage is available for a limited time, which can elicit agonistic behaviour in group-fed horses (Burla et al., 2016).

3.3. *Integration of the response: herbage intake*

In spite of the higher GTP and HDMIR, the daily intake of herbage (HDMI) is often constrained in cattle and sheep exposed to severe AT (**Fig. 5a and 5b**). These figures suggest that, in practice, two classes of AT could be tentatively envisaged: mild (AT ~8-6 h/d) and moderate to severe (AT <6 h/d). However, the diversity of animal requirements, pasture conditions and supplementation treatments among studies suggests adopting a cautionary attitude towards this classification, which warrants a further analysis. For instance, comparing AT of 2, 4, or 6 h/d, the last was regarded as the optimum to maximize herbage intake in mid-lactating ewes grazing Italian ryegrass of medium quality (Molle et al., 2014b). In contrast, this threshold was set to 4 h/d in mid-lactating ewes grazing high quality berseem clover (Molle et al., 2017) and in late lactating ewes grazing a low-quality natural pasture (Valenti et al., 2017). In goats subjected to PTG, HDMI was higher with 11 h/d than 7 h/d AT (Charpentier and Delagarde, 2019), but with a lower herbage quality there was no difference between 6 h/d and 22 h/d (Keli et al., 2017). These results suggest that PTG could be shorter than 6-7 h/d only if herbage quality (low NDF, moderate to high CP) and accessibility are high and/or animal requirements are low. The

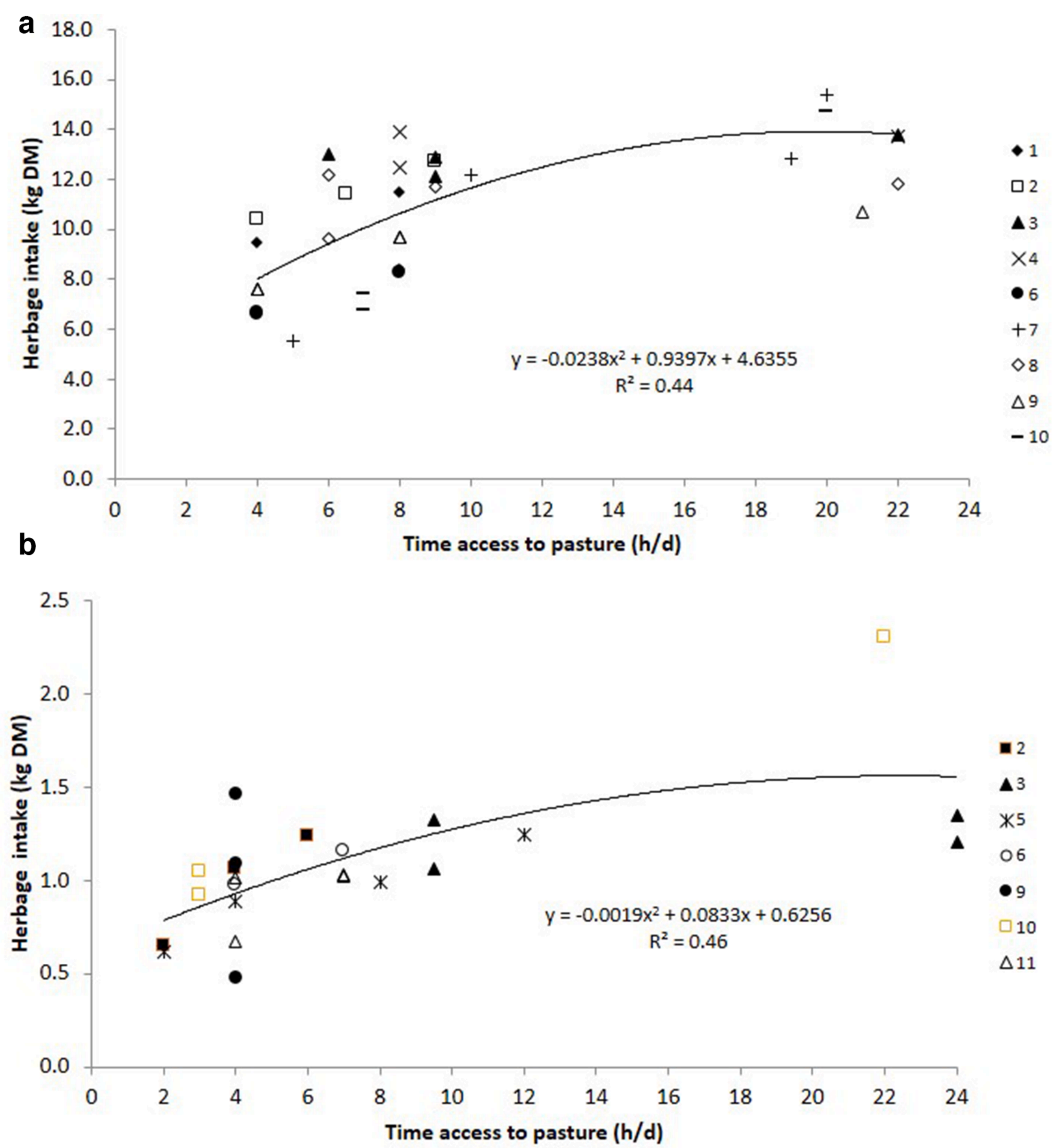

Fig. 5. Herbage intake in dairy cows (a) and sheep (b) submitted to part-time grazing. See legend of Fig. 2 for details on data source.

interaction between AT and herbage accessibility was well described by Iason et al. (1999) for meat producing sheep. These authors found that HDMI was constrained in overnight locked sheep, compared to unrestricted sheep continuously grazing pasture, when the animals were kept at 3 cm sward height, but when sward height was of 5.5 cm no differences occurred. Even in horses, HDMI was markedly reduced when they were exposed to AT $\leq$ 6 h/d as compared with AT of 9 or 24 h/d (Glunk and Siciliano, 2011). In general, in horses AT to pasture should be at least of 8-10 h/d to allow for *ad libitum* herbage intake. However, this level may not suffice to meet the energy requirements in lactating mares (Collas et al., 2015) and can be risky in leisure and sport horses prone to equine metabolic syndrome (Durham et al., 2018).

Among the factors underlying the variability of herbage intake response to part-time grazing herbivores, we can evoke differences in nutrient requirements, herbage composition, especially in regard to CP and NDF concentrations, and confounding effect of the replacement of the grazed herbage with supplements. In fact, only very few studies assess the effect of AT to pasture in unsupplemented herbivores. This could provide an uncounfonded response to AT. In contrast, in most of the studies PTG response is evaluated in ruminants supplemented at flat rate (e.g. Molle et al., 2017) or at variable rate, usually increasing with the severity of AT restriction (e.g. Perez-Ramirez et al., 2008;, in cows; Valenti et al., 2017, in sheep). When supplemention level is varied among AT treatment groups, it is not possible to draw any conclusion on how herbage intake is affected by the AT *per se* but rather by the feeding regimen, inclusive of herbage and supplements.

Pasture availability and herbage quality are typical modulating agents of the relationship between access time to pasture and herbage intake (Hodgson, 1990). Dobos et al. (2009) found that herbage intake of dairy cows strip-grazing a C4 grass, kikuyu (*Pennisetum clandestinum*) was not severely reduced if AT to pasture was at least 4 h/d with pre-grazing compressed sward height of 10 cm, but could be even 2 h/d with a higher sward height (13 cm). In milked ewes, herbage NDF concentration was the main limiting driver of herbage DMI, when access time ranged from 2 to 6 h/d (Molle, 2014). Therefore, accessing for few hours to a legume pasture can better compensate a severe access time restriction than extending AT in a grass based pasture (Molle et al., 2014a). Also, the modulating effects of level and type of supplementation cannot be neglected. In general, if herbage availability is not limiting, herbage intake is reduced by the supplement [substitution effect, see review (Tedeschi et al., 2019)]. In ruminants with moderate to low requirements, supplement intake can decrease along with the increase of AT to pasture as shown by Hernandez-Mendo and Leaver (2004) in cows supplemented with maize-silage ad libitum.

The presence of plant secondary metabolites in the grazed herbage can also limit herbage intake under restricted time access to pasture. A recent example is the lower herbage intake in late-lactating dairy ewes grazing Sulla with AT to pasture of 8/d than in counterparts with AT of 22 h/d (Bonanno et al., 2016). Condensed tannins (CT) contained in sulla leaves and flowers can in fact slow down the grazing activity if sheep have no chance to dilute their rumen content, for instance grazing a CT-free forage, as demonstrated using anti-tannic substances such as the polyethylene glycol (Molle et al., 2009). Recent results by Feng et al. (2016) suggest that increasing the species richness on offer with forages belonging to different functional groups (grass, legume and forbs containing plant secondary metabolites) can increase the eating time and herbage intake in stall-fed sheep with a AT to feed of 2 h/d. Interestingly, it seems that the dietary diversity affected the end of the meal predominantly, with sheep allowed to choose among several forages presenting a greater proportion of time devoted to eating than sheep confronted with a lower dietary diversity. This result suggests that a targeted forage diversity at pasture can improve the efficiency of part-time grazing ruminants, as asserted by Provenza, Meuret and Gregorini (2015).

At equal AT, the actual time of the day of the grazing sessions also matters. In fact, due to the increase of DM, water soluble carbohydrates (WSC) and precursors of beneficial FA (Delagarde et al., 2000; Gregorini, 2112), and a more favourable hormonal milieu (Gregorini, 2012) herbage intake, performance and product quality tend to increase when the grazing occurs at PM time compared to AM time, as reviewed by Gregorini (2012). Recent results in dairy sheep back the work of Gregorini (2012): e.g. Molle et al. (2016), found higher herbage intake in dairy sheep allocated, for 4 h/d, to an Italian ryegrass pasture in the evening rather than in the morning. Likewise, Avondo et al. (2008) found an increase of WSC (20 vs. 17 % DM) in the herbage selected by Girgentana goats grazing *Lolium multiflorm* Lam. in the afternoon than in the morning. Grazing in the afternoon is probably more effective during Mediterranean winter and early spring than in late spring, when heat load can be significant, depressing intake and performance (Finocchiaro et al., 2005).

Only one study addressed this topic with reference to horses, to the best of our knowledge. Chavez et al. (2011) compared AM (7:00-13:00) vs PM (12:30-20:30) access time to pasture in geldings (588 kg BW) finding a higher intake of fescue pasture in PM than AM grazed horses (6.6 vs 5.6 kg DM, $P<0.05$). This result suggested the authors to discourage the delayed turn-out to pasture, due to the higher risk of laminitis associated with higher intake of WSC and NSC. In fact, an early morning access would probably be safer for this purpose. Early morning (from dawn to midday, Longland and Byrd, 2006) or late evening access (from 20:00 onwards on cool-season grasses, Weinert-Nelson et al., 2022) are concerned options since WSC decrease during the night. However, late evening allocation can be risky if horses are not previously supplemented with hay, to prevent high herbage intake rate at turnout due to long fasting. Beside the duration and the actual time of access to pasture, the intake of NSC depends on other factors such as the grazed forage (higher in cool-season C3 than summer season C4-grasses e.g. DeBoer et al., 2018) the season (higher in spring and late autumn) and sward height (higher in tall (stemmy) than short (leafy) patures (e.g. 30-40 vs 15 cm, Siciliano et al., 2017). The intake of WSC can be effectively reduced (even by 80%) by the use of grazing muzzles (Longland et al., 2016) although attention must be paid while training the animals to prevent welfare issues (National Equine Welfare Council, 2015). According to some studies intakes above 7 g/kg BW of fructan (the main component of herbage NSC) can substantially increase the risk of laminitis (Longland and Byrd, 2006). Therefore, the AT to pasture should be planned taking into consideration the content of NSC in the herbage and in total diet (< 12% DM in in horses at risk of equine metabolic syndrome, Frank, 2009).

3.3.1. Models for the prediction of intake of herbage in PTG herbivores

The herbage intake of ruminants and horses subjected to PTG has been targeted in some modelling efforts. Although nowadays many static or dynamic models are available to predict the intake of cattle (recently reviewed by Tedeschi et al., 2019) and sheep (Pulina et al., 2013), not many models take into account the AT as a determinant of herbage intake. In cattle, these are, to the best of our knowledge, GrazeIn, a mechanistic partially dynamic model (Delagarde et al., 2011), and Mindy (Gregorini et al., 2013). The latter is a mechanistic dynamic model which can devise and evaluate grazing scenarios at a very fine temporal scale (min). In sheep, only empirical models are available to estimate herbage intake using AT as independent variable, such as the empirical regression equations (Molle et al., 2014b) and the ordinary and multivariate partial least square regressions reported by Molle (2014). These models are based on a dataset (N =114) of intake measurements of sheep grazing grass and legume Mediterranean forages with AT of 2, 4 or 6 h/d. The best-fitting ordinary regression model included only three explanatory variables, namely sheep milk yield (MY, g/d), NDF content of the grazed herbage (NDF_h, % DM) and access time, which was also quadratically related to the herbage intake:

$$\mathrm{HDMI\,(g\,DM)} = 802 + 0.32\,\mathrm{MY} - 28.98\,\mathrm{NDFh} + 545.53\,\mathrm{AT} - 51.74\,\mathrm{AT}^2 \quad \mathbf{R^2 = 0.82, RMSE = 195, P < 0.001} \tag{3}$$

It is worth noting that, in this equation NDF_h had a major negative impact, markedly decreasing HDMI as AT was reduced, while the effect of milk yield was positive in terms of HDMI but much less marked.

In horses, a compilation of data (N=23 mean data) by Siciliano (2012) sourced a regression equation to estimate herbage intake scaled to horse body weight ($HDMI_{BW}$, g DM/kg body weight), including as explanatory variable only the AT:

$$\mathrm{HDMI_{BW}} = 5.12\ \mathrm{AT}^{0.5} - 2.86, \mathbf{R^2 = 0.70, P < 0.001} \tag{4}$$

To the best of our knowledge there are no intake prediction models for goats which explicitly account for AT.

4. Effects of AT on diet selection and diet digestibility

Few studies have assessed the effect of time restriction to pasture on selected herbage quality and hence diet quality and nutrient intake. Ginane and Petit (2005) found that heifers exposed to a AT restriction of 5 h/d gave priority to the quality rather than the quantity of selected herbage, spending proportionally more time grazing vegetative than reproductive patches than counterparts exposed to them for 24 h/d. In a more recent paper on lambs grazing a Mongolian steppe characterized by relatively high species diversity (Zhang et al., 2017), lambs grazing for 2 and 4 h/day showed a higher dietary contribution of *Leymus chinensis,* a perennial grass, than lambs grazing for 8, or 12 h/d. Interestingly, this plant species showed the highest energy content among the species on offer, possibly due to the a high level of lipids, namely α-linolenic acid. Even under controlled stall-feeding conditions, goats with access to diverse feed and submitted to restricted access time, shifted their dietary choice in favour of high-quality ingredients (Görgülü et al., 2008). This would suggest that ruminants submitted to restricted AT to feed tend to compensate for it by increasing energy and maybe protein intake rate.

Diet selection is a time-expensive process, so it is hardly explainable how a grazer can conceal it with a faster intake rate, unless sward structure can favour the coupling of quantity and quality. For instance, in some species (e.g. white clover) legume leaves are available on the upper grazing layer, favouring the coupling of quantity and quality in herbivores compelled (or motivated) to eat fast (Baumont et al., 2004).

There is also a shortage of information on the fate of the ingested herbage at rumen and post-rumen levels. In general, the shorter the grazing session, the smaller the size of DM and NDF rumen pools, which usually peak at the end of the grazing period (dusk meal, Taweel et al., 2006). Nonetheless, the rate of increase in rumen pools is higher at beginning than at the end of a grazing session (Chilibroste et al., 1989). The raise depends on rumen fill, being higher in fasted animals, and nutritive value of the grazed forage. For instance, Williams et al. (2014) showed that cows grazing Persian clover had a relatively slow increase in rumen pool sizes after 3 hours of grazing as compared with those measured by Chilibroste et al. (1989) on a grass-based pasture. This could be explained by the lower NDF level of the legume.

Rumination is postponed and preliminary mastication reduced in part-time grazing ruminants. In severely AT restricted ruminants, digestion and passage rate can be slowed down during the time at pasture. Therefore, constraints in time access successfully compensated by the feeding behaviour (higher GTP and HDMIR) can impair digestion later on, particularly if HDMIR had been accelerated by factors such as previous fasting and possibly afternoon grazing meals.

The impairment of digestion due to the reduction of AT to feed has been recently backed by Perez-Ruchel et al. (2013), who found lower DM intake, and rumination time during the first 6 hours after meal offer, and higher passage rate in sheep fed fresh *Lotus corniculatus* with restricted access time of 6 h/d as compared with unrestricted counterparts. Also, DM and NDF apparent digestibility coefficients were numerically lower in time-restricted than -unrestricted sheep (61 vs. 64% and 41 vs. 48%, respectively). Similar results were found in an experiment on restricted time access to self-feeders delivering a complete diet to housed goats: the most severely time-restricted goats (2 h/d) showed a lower numerical value for both DM (70.6 vs. 74.7 %, control) and NDF (44.7 vs. 54.8 %) apparent digestibility coefficients than the time unrestricted control (Silva et al., 2018). In contrast, restricting AT to fresh forages to individually fed heifers from almost 24 h/d to 4 h/d did not result in a reduction of either DM or NDF apparent digestibility but tended to lower ruminal microbial protein synthesis (from 46 to 17 g of microbial N/d, $P < 0.08$), (Felix et al., 2017).

Overall, these limited research data suggest that severely restricting access to feed or pasture could impair diet digestibility. Although this constraint is complex and not easy to tackle, the use of additives such as yeasts (Perez-Ruchel et al., 2013) or buffers such as sodium bicarbonate (Silva et al., 2018) may alleviate its effect.

Horse data reveal that even for this animal species, shortening AT can have some drawbacks on digestion, with lower fecal pH due to the fast-big meals resulting from PTG (Glunk et al., 2013). However, no evidence of these problems was detected by monitoring faecal pH in horses with a moderate restriction of AT (12 h/d vs. 24 h/d; (Siciliano

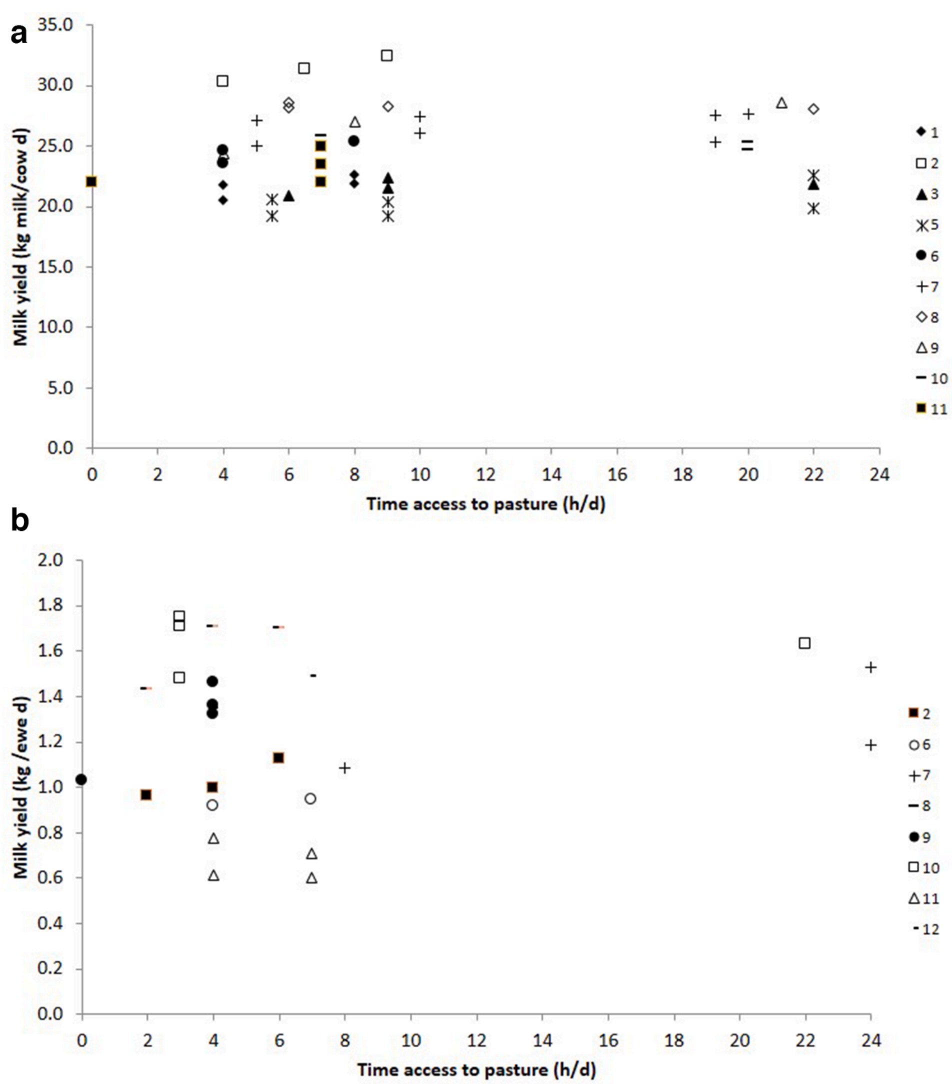

Fig. 6. Milk yield in dairy cows (a) and milked ewes (b) part-time grazing. See legend of Fig. 2 for details on data source.

and Schmitt, 2012). In the horse, differently from ruminants, providing episodically large meals based on concentrate can result in hypovolemia and dysruption of gut motility pattern with fast gastro-enteric transit, which can be conducive to digestive problems at large intestine level: colitis, impaction, dispalcement/torsion and diarrehea (Clarke, Roberts and Argenzio, 1990). These are due to altered fermentation of carbohydrates, with raise of lactic acid content, lower pH and absorption of endotoxins. Gastro enteric transit in horses is dependent on the square root of the meal volume (Clarke, Roberts and Argenzio, 1990), thus it parallels the herbage intake trend in horse under restricted AT to pasture (Siciliano, 2012). Therefore, short time allocation of horses to a lush pasture with high NSC (> 15 % DM) is prone to result in these problems besides laminitis, particularly if horses are fasted before grazing.

5. Effects of AT on energy expenditures (EE)

Data are scanty and basically refer to goats and horses. In a long run experiment with goats in different physiological stages, using the heart rate/O_2 pulse method, Trovar-Luna et al. (2011) found a higher total EE in all-day than night-locked grazing goats (754 vs. 687 kJ/kg $BW^{0.75}$). Furthermore, the EE associated with locomotion was numerically higher in the all-day grazing goats (64.1 vs. 53.2%, of maintenance requirements, inclusive of thermoregulation, respectively). In an experiment on growing kids, Behran et al. (2005) found a trend of EE increasing with the length of access to pasture, amounting to 4.96 (4 h/d), 5.13 (8 h/d), and 6.19 MJ/d (24 h/d). This result agreed with the longer GT and greater number of steps in the goats exposed to the long AT.

In dairy goats, results by Keli et al. (2017), confirmed that PTG can be convenient for sparing energy: goats at pasture for 8 h/d walked for less time (0.90 vs 1.75 h/d) and spent less energy (667 vs 745 kj/kg $BW^{0.75}$) than goats having unrestricted access to pasture (22 h/d). The grazing activity cost was estimated as 27% and 11% of maintenance energy requirements for the unrestricted and moderately restricted goats, which resulted in higher milk performance in the 8 h/d AT goats.

Overall, the response to part-time grazing in terms of EE, or walking activity (e.g. (Chen et al., 2013 in lambs) suggests that, in many cases, a moderate time restriction can result in lower EE and possibly in a better efficiency of energy utilization at animal level. Interestingly, in a comparison between full time access to pasture versus zero-grazing (same diet – different feeding management), dairy cows at grazing spent 19% more energy in the first 6-h access period than counterparts fed freshly cut herbage, providing a first approximation of extra EE cost of PTG, independent of diet quality (Dhome-Meier et al., 2014).

In the horse, EE for locomotion is fundamental because, it can be regarded the main source of energy requirement in adult horse under work after the energy requirements for maintenance. Horse at pasture increase their EE, but, in some cases, the intake of energy associated to long AT is much higher than the corresponding EE. In yearling Thoroughbreds with AT of 10 or 17 h/d (including night hours), the EE was estimated to be higher by 10 Mcal digestible energy in those grazing for longer (1 Mcal/h of AT) (Asai et al., 1999). Proper estimation of herbage intake and EE is fundamental in this species for its welfare and sport performance but also for avoiding overweight and obesity, which has a high prevalence in some countries such as the UK (Stephenson et al., 2011). A recent survey on athlete and leisure horses in Germany (Schmitz et al., 2020) showed that the walking distance of horses, measured by global positioning system, unexpectedly increases exponentially along with the decrease of AT to pasture. This concurs to explain why horses severely restricted for AT to pasture are unable to compensate AT with an increase in GTP. They in fact tend to prioritize exercising over feeding (Schmitz et al., 2020). This may have negative implications also on pasture persistence, due to the increased trampling effects of horses with very short AT to pasture.

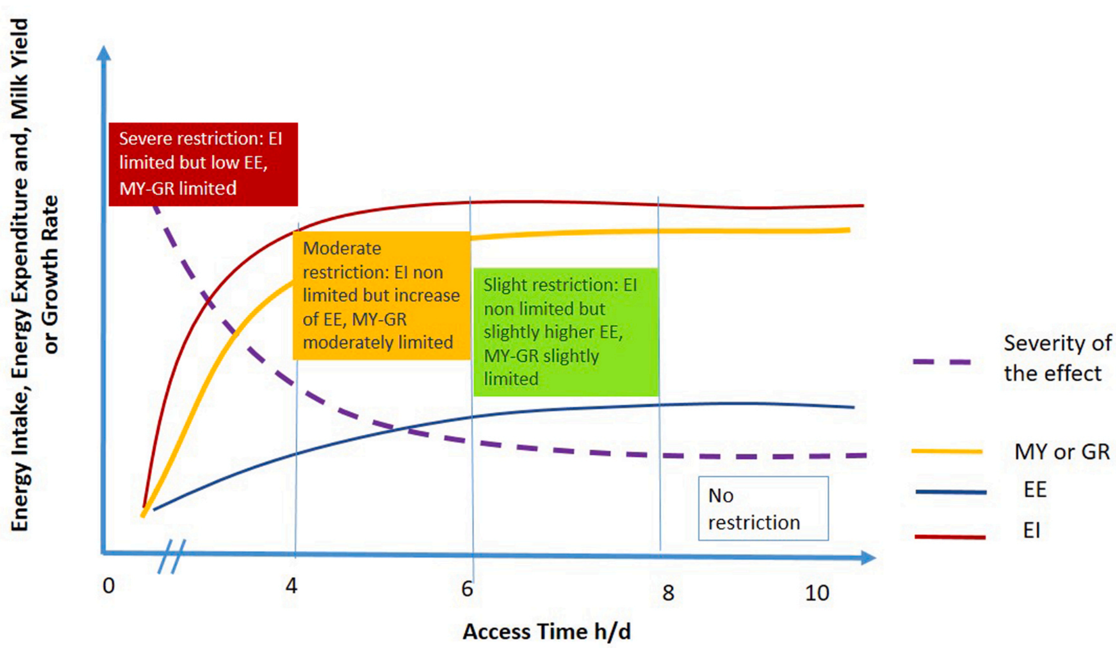

Fig. 7. Conceptual model showing the pattern on per-animal basis of energy intake (EI, Mcal/d), energy expenditures (EE, Mcal/d), and energy retained in the body or exported in products [(milk yield (MY, Mcal/d) or growth rate (GR, Mcal/d)] along with the increase of access time (AT) to pasture. The model illustrates the pattern of response in PTG ruminants supplemented with a rationed and fixed level of concentrate. As time onto pasture increases the intake rate and the proportion of time devoted to grazing decrease but AT increases in a way that the EI can reach its peak when restriction is moderate. In the meantime, EE increase but initially they are low because the ruminant prioritizes fast eating, with long meals and infrequent changes of feeding stations. Then EE plafond because most of the locomotion expenditures are associated to grazing. Performances depends on the energy balance: they tend to peak after the EI peaks because the balance is still positive. This model allows to tentatively classifying the effect of time restriction into four classes of severity from severe to nil.

6. Effects of AT on ruminant performances

6.1. Direct effects

In ruminants, the reduction of AT can result in lower performance. However, the actual response depends on several factors, such as severity of time access restriction, daily period of access (e.g. day vs. night), level of animal requirements, accessibility and quality of the pasture on offer, and supplementation level. Moreover, mobilization of body reserves may sometimes mitigate the constraint on nutrient intake related to short AT to pasture. As can be seen in **Fig. 6a and 6b**, overall milk production of dairy cows and dairy sheep are often not apparently affected by AT, particularly when it is higher than 6 h/d. In lactating meat goats, Trovar-Luna et al. (2011) showed a lower milk yield in early but not in late lactating does, grazing a grass-legume pasture at 12 h/d of AT (night-locked goats) compared with counterparts at pasture for 24 h/d. More recently, in Alpine dairy goats several papers conveyed that AT of at least 7-8 h/d can optimize milk yield, provided that good quality supplementation is provided (Keli et al., 2107, Charpentier and Delagarde 2018 and 2019).

In growing cattle, Ginane and Petit (2005) found better performance in the unrestricted (24 h/d) than in the restricted AT (5 h/d) heifers. Valenti et al. (2014) compared growing Merinos lambs submitted to 8 h/d AT and 4 h/d AT in either morning or afternoon hours, grazing a perennial ryegrass sward. These authors reported better performance in the less restricted group, in terms of final body and carcass weights, but with undifferentiated dressing percentage among groups. Contrarily, in supplemented lambs growing on the Chinese steppe, increasing the AT from 2 to 12 h/d did not result in better average daily gains, despite some period × AT interaction (Zhang et al., 2014). In growing kids of meat breed, 24 h/d access to pasture resulted in minor, but detectable, advantage as compared with night-locked counterparts in terms of BW daily gain (Trovar-Luna et al., 2011). Berhan et al. (2005), comparing shrunk body weight accretion of growing Boer goats submitted to 4 h/d, 8h/d, or 24h/d of AT to pasture, found that the 4 h/d treatment group showed a numerically lower shrunk BW accretion (69 g/d), without differences with the performances of the other groups (85 g/d for 8 h/d, and 83 g/d for 24 h/d; P>0.05).

Sparse studies on cattle (mainly *Bos indicus* or crossbred) grazing tropical pastures in Africa, overall, lend support to the severity ranking of the effects of AT restriction on performance: for instance while Jung et al. (1985) detected lower BW gain and lower milk yield in cows with AT of 4.5 than 9 h/d, Smith et al. (2006) did not find any advantage in extending the grazing session from 7 to 11 h/d even when providing roughage as a supplement to night-locked cows. Ayantunde et al. (2008) detected only a small, not-significant increase in BW in cows exposed to 9 h/d rather than 6 h/d AT to pasture. In these studies, however, pasture quality and availability were generally moderate to low, as it can be expected in these farming areas, and cattle had to walk to the pasture and back to the corral even twice a day to drink (Smith et al., 2006), thus exacerbating the increase of energy expenditures associated with the extension of daily grazing sessions.

The results of studies on the effects of AT on energy expenditures and ruminant performances, can be resumed in the conceptual model depicted in **Fig. 7**. This shows the expected pattern of energy intake (EI), EE and energy retained in the body or exported in products (milk yield MY, or growth rate) along with the increase of AT to pasture. In particular, the model illustrates the pattern of response in PTG ruminants supplemented with a rationed level of concentrate, based on the expected performance, and with ad libitum conserved forages, the latter having CP and NDF concentrations lower and higher than the pasture, respectively. Using the energy balance as main performance driver, this model classifies the severity of AT restriction into 4 classes: severe (less than 4 h/d), moderate (4-6 h/d); slight (6-8 h/d) and nil (>8 h/d). These thresholds should be regarded as tentative: the actual restriction will depend on the level of performance, the intake and nutritive value of the grazed herbage, the level and nutritive value of supplementation.

Relatively few studies have fully addressed the effect of AT restriction to pasture on ruminant product quality. In dairy cows, milk composition has been sometimes influenced by the access time, but overall, there is no apparent trend in milk fat and protein contents along with changes in time restriction. Data on dairy sheep are too few for allowing a proper comparison (Molle et al., 2014b; Molle et al, 2017; Garcia-Rodriguez et al., 2005; Alvarez-Rodriguez et al., 2007). Although lower values of milk fat and protein contents are detectable in non-restricted as compared with restricted ewes, this is probably basically a dilution or 'study effect'.

The effect of restricted or unrestricted AT on milk fatty acid profile has recently become a popular research subject with reference to dairy cows (e.g. Rego et al., 2008). In a recent study by Atkins et al., (2020) on high producing dairy cows fed total mixed ration, pasture AT of 6 h/d was sufficient to maximize the level of linolenic acid (C18:3 c9 c12 c15 n-3) and conjugated linoleic acid (C18:2 c9 t11) in milk ($P < 0.022$ and $P< 0.052$, respectively). These results confirm those by Barca et al., (2017) who maximized the content of linolenic acid and n-3 FA in milk offering 6 h/d of pasture as compared with stall-feeding a total mixed ration. No significant improvement in milk FA composition was found in cows having access to pasture for 9 h/d, in two separated grazing sessions. Findings on dairy sheep and goats lag behind. De Renobales et al. (2012) focussed on the effects of AT and supplementation on sheep milk, finding an increase of beneficial FA (e.g. c-9, t-11 CLA and ω 3 fatty acids), in sheep grazing at least for 4 h/d without fat-enriched supplements. Cabiddu et al. (2017) reported similar results with AT of 3 as compared with 22 h/d, but with high level of fat-based supplementation. In these reports, however, comparison between PTG and control ewes were absolute (stall-fed control vs 4 h/d in De Renobales et al. (2012) and 22 vs 3 h/d in (Cabiddu et al., 2017).

Beside the effect of duration of pasture allocation, the actual timing of pasture allocation is also important to enahance the content of beneficial FA in ruminant milk. Avondo et al. (2008) for example found a higher content of these FA in goats fed berseem clover in the afternoon as compared with counterparts fed in the morning, thanks to the higher content of FA precursors in the herbage mown and fed in the afternoon.

In meat sheep, comparing lambs allocated to Mongolian pastures for 2, 4, 8 or 12 h/d, the level of PUFA in meat was optimized with 4 h/d access, due to high level of intake of *L. chinensis*, a plant particularly rich in linolenic acid (Zhang et al., 2014). This was explained by the greater preference shown in the lambs having a longer access during afternoon hours to less spread but probably more palatable species, much richer in non fiber charbohydrates (*C. squarrosa*) and protein (*A. ramosum*) than the *L. chinensis*.

6.2. Carry-over effects

The effects of feed deprivation and, in particular that of restricting AT to pasture, may depend not only on its intensity (severity) but also on the duration of time restriction. Only few studies have addressed so far this point. Its seems that the longer the application of the grazing management, the more the ruminant can adapt to it, using different behavioural cues and physiological mechanisms to offset the constraints imposed by the limited availability of time for grazing. Conversely, if restriction is severe, it can be argued that the herbivore can experience a marked distress, becoming unable to accommodate the uncomfortable conditions, losing performance and weight.

Residual effects of PTG may appear later, and persist even more than a month after its discontinuing. In fact, dairy cows at pasture for 21 h/d that had been submitted for 5 weeks to AT to pasture of 4 or 8 h/d, produced less milk in the following month than control cows kept at pasture for 21 h/d across all the study (Delaby et al., 2008). The loss of milk increased with restriction severity: 2 kg/cow (8 h/d) vs. 3.5 kg/cow (4 h/d). In another study, after the 15 days following discontinuing of time restriction, the most severely restricted cows tended to have lower milk protein concentration than time-unrestricted counterparts, suggesting the persistence of an energy deficit in these cows (Kennedy et al., 2009). In dairy sheep, a carry-over effect was detected in terms of reproduction performances, with a lower fertility (n.s.) and prolificacy ($P<0.05$) at the first mating in the sheep exposed to AT to pasture of 2 h/d as compared to 4 and 6 h/d in the previous two months (Porcu et al., 2014). This is in line with previous results on the negative carry over effect of grazing management in dairy sheep continuously stocked in a pasture kept at 30 mm compressed sward height during mid-lactation (Molle et al., 1995).

While the transition from a severely restricted to a more generous AT to pasture can result in negative carry-overs, paradoxically, the residual effect of shifting from 100% stall feeding to PTG is usually positive, with good milk persistence and prompt improvement of milk FA composition, as shown in mid lactation cows by Barca et al. (2017). This backs the point that ruminant performance and well being is improved by some grazing and resting outdoor (Charlton and Rutter, 2017), particularly if weather conditions (THI, rainfall) are favourable or neutral. These findings are relevant for setting up dynamic mixed feeding systems (TMR in early lactation followed by TMR + grazing) able to improve milk quality and animal welfare.

7. Effects of AT on animal welfare

Although PTG can be beneficial for the animal welfare results on the effect of restricting the access time to pasture on specific welfare indicators are rather rare, with particular reference to issues related to animal behaviour. Does the restriction of AT to pasture infringe the 4th freedom, i.e. the freedom to display most normal pattern of behaviour [Brambell report, quoted by Dwyer and Lawrence (2008)]? Do the grazers suffer from frustration when the allocation to pasture is limited to few hours daily? Or conversely, do the pleasure of grazing fresh herbage rather the eating a standard indoor diet (hedonic response) and the "happiness" to choose even a short grazing experience rather than staying all time housed (eudaimonic response) overcome this putative frustration (Becks and Gregorini, 2020)?

There are no obvious answers to these questions, because research has often overlooked the implications of PTG on animal welfare in favour of a productivity-driven approach. Whereas several papers report on the effects of PTG on feeding behaviour indicators, (grazing and ruminating time) or body condition score (Hernandez-Mendo and Leaver, 2004), much less focus has been given on adequate resting indicators, such as lying time, and frequency and duration of lying bouts (e.g. Chapinal et al., 2010; Kismul et al., 2018; Crump et al., 2019; Kismul et al., 2019). Overall, these papers show that providing restricted access to pasture, particularly during the night, is beneficial to enhance the time the cows lie down outdoor, which is usually associated with lower incidence of lameness compared to stall fed cows. However, a recent survey (Armbrecht et al., 2019) in Germany suggests that extending AT above 10 h/d is needed in order to maximize these benefits.

As for the positive aspects on welfare, the preference for grazing rather than stall-feeding and the factors that affect the the outdoor vs. indoor accommodation in cattle have been recently reviewed by Charlton and Rutter (2017). They found that in many circumstances cow prefer to spend their time outdoor more than indoor but results vary markedly. They range from 9% to more 70% of available time spent outdoors, depending on factors such as grazing experience, weather conditions, distance between barn and pasture, and time of the day, with higher preference for pasture during the night (basically for resting purpose). However, most of preference and motivational studies do not account for restricted access to pasture. Moreover, there is a lack of studies on the welfare issues of small ruminants subjected to PTG.

The implication of PTG on horse welfare has been also underexplored so far. Restricting the time outdoor (turnout time) from 12 h/week (2 h/d for 6 day) to 2h/week (2h for a single day) has been shown to elicit a higher frequency of undesirable behaviour in regularly ridden horse, such as bucking at the expense of grazing (Chaya et al., 2006). In general, permanently stabled horses display a higher training time and more frequent unwanted jumping and bucking behaviours during groundwork and while ridden than pasture-kept horses (Rivera et al., 2002). For this species, many studies have shown that the increase of the number of meals and dietary diversity - i.e. mimicking the spatio-temporal hetereogenity of grazing - usually results in lessening the prevalence of stereotypies, such as wood chewing and crib biting (Thorne et al., 2005, Hothersall and Casey, 2012). Moreover, a steady eating pattern, with small meals spread over the 24 h (trickle feeding) common under 24 h/d grazing conditions, is crucial for preventing digestive and metabolic problems, such as the equine metabolic syndrome, often associated with insulin dysregulation, which is in its turn associated with laminitis and obesity (Frank and Tadros, 2014). A relatively steady eating pattern can be achieved in practice even in horse under PTG, providing a semi-continuous access to conserved forages during housing using "slow feeders" (Rochais et al., 2018) and adding chaff to the concentrate.

8. Concluding remarks and future research needs

Cattle and sheep can benefit from PTG. In fact, ruminants are effective in compensating for the restricted AT to pasture due to the increase of GTP and herbage intake rate, provided that restriction is not too severe (at least 6-8 h/d of AT in dairy cows and dairy goats, 4-6 h/d in dairy sheep), herbage allowance is not limiting or supplementation is adequate. This depends on the reduction of energy expenditure, and on occasion, the selection of a better diet. Nevertheless, due to lower ingestive fibre comminutation, fibre digestibility can be reduced, but only under severe time restrictions (<4 h/d). Moreover, in ruminants, milk and meat content of beneficial FA are usually higher in PTG than in stall-fed ruminants. For the improvement of milk fatty acids composition, access on grass-based pastures should be at least 6 h/d in cows supplemented with total mixed ration or even 4 h/d, in dairy ewes supplemented with concentrate and hay. Timing the grazing session of ruminants in the afternoon and evening hours is a good strategy to match pasture quality and animal attitude to forage intensively and efficiently, favouring intake, performance and produce quality.

Also sport and leisure horses can benefit from PTG. However, although they are similarly effective than cattle and sheep in compensating for the restriction of AT, on average they show lower intake rate scaled to MW. This would suggest to allocate longer AT to this species than to ruminants. Moreover, PTG of housed horses can be helpful to meet their demand of free exercise and socialization and improve their well-being, provided that herbage intake is controlled to prevent excess of NSC, which makes horses prone to pathologies such as laminitis. These risks are greater when horses are allowed to graze in the afternoon. In contrast, risks are lower if grazing is planned from early morning to midday or overnight, provided that hay is previously fed to prevent high herbage intake rate at turnout.

The evaluation of the effects of daily frequency of AT deserves further research efforts. Particularly in this area, the measurement of ingestive behaviour should be coupled with that of distance walked and EE, to gain knowledge on the mechanisms underlying animal response.

The timing of supplementation with respect of the grazing sessions, for sake of brevity, was not examined in this review but the complementarity and synchronized availability of pasture- and supplement-sourced nutrients is another overlooked area that warrants further delving.

Fast-grazing associated to severe restriction of AT to pasture apparently fits better to the grazing of monocultures of forage species, featured by a moderate or low content of fibre, legumes or good quality grasses, possibly associated as stripes. Also the individual animal ability to adapt to short-grazing sessions should be examined more in depth, considering both animal and microbiota genome. These are other knowledge gaps to be filled.

Another subject that warrants further research effort is the effect of PTG on herbivore welfare, not only in terms of meeting basic physiological needs (adequate feeding, drinking, thermoregulation and resting) but also with reference to negative (the perceived risks of predation) and positive mental conditions, such as the hedonic (feelings of pleasure) and eudaimonic (feelings of purpose) well-being states.

Finally, a more holistic research is needed to assess these effects at a system level and across the whole grazing season, to detect the long term direct and residual effects of PTG, including the impact on greenhouse gas emissions. To this end, models would be greatly helpful to envisage scenarios, predict animal responses and screen hypotheses to be prioritized for testing under experimental conditions.

Declaration of interest

All the Authors declare there is no conflict of interest in this publication

Acknowledgements

Part of the material of this manuscript stems from a PhD thesis (Molle G., 2014) accessible online. The authors wish to gratefully thank Dr. Ana Helena Francesconi for her significant help in the editing of this manuscript.

References

Allden, W.G., Whittaker, A.McD, 1970. The determinants of herbage intake by grazing sheep the interrelationship of factors influencing herbage intake and availability. Aust. J. Agric. Res. 21, 755–766.

Alvarez-Rodriguez, J., Sanz, A., Delfa, R., Revilla, R., Joy, M., 2007. Performance and grazing behaviour of Churra Tensina sheep stocked under different management systems during lactation on Spanish mountain pastures. Livest. Sci. 107, 152–161. https://doi.org/10.1016/j.livsci.2006.09.011.

Armbrecht, L., Lambertz, C., Albers, D., Gauly, M., 2019. Assessment of welfare indicators in dairy farms offering pasture at differing levels. In: Animal, 13. © The Animal Consortium 2019, pp. 2336–2347. https://doi.org/10.1017/S1751731119000570.

Arnold, G.W., Dudzinsky, M.L., 1978. Ethology of free ranging domestic animals. Elsevier, Amsterdam.

Asai, Y., Matsui, A., Osawa, T., Kawai, M., Kondo, S., 1999. Digestible energy expenditures in grazing activity of growing horses. Equine exercise physiology 5 Equine vet. J., Suppl. 30, 490–492. https://doi.org/10.1111/j.2042-3306.1999.tb05271.x.

Atkins, N.E., Cianchi, C., Rutter, S.M., Williams, S.J., Gauld, C., Charlton, G., Sinclair, L. A., 2020. Performance, milk fatty acid composition and behaviour of high-yielding Holstein dairy cows given a limited grazing period. Grass Forage Sci 75, 181–191. https://doi.org/10.1111/gfs.12471.

Avondo, M., Bonanno, A., Pagano, R., Valenti, B., Di Grigoli, A., Alicata, M.G., Galofaro, V., Pennisi, P., 2008. Milk quality as affected by grazing time of day in Mediterranean goats. J. Dairy Res. 75, 48–54. https://doi.org/10.1017/S0022029907003019.

Ayantunde, A.A., Fernandez-Rivera, S., Hiernauxc, P.H., Tabod, R., 2008. Implications of restricted access to grazing by cattle in wet season in the Sahel. J. Arid Environ. 72, 523–533. https://doi.org/10.1016/j.jaridenv.2007.06.006.

Bakker, E.S., Reiffers, E.R.C., Olff, E.H., Gleichman, J.M., 2005. Experimental manipulation of predation risk and food quality effect on grazing behaviour in a central-place foraging herbivore. Oecologia 146, 157–167. https://doi.org/10.1007/s00442-005-0180-7, 2005.

Barca, J., Carriquiri, M., Olazabal, L., Fajardo, M., Chilibroste, P., Meikle, A., 2017. Milk fatty acid profile from cows fed with mixed rations and different access time to pastureland during early lactation. J. Anim. Physiol. Anim. Nutr. 102, 620–629. https://doi.org/10.1111/jpn.12826.

Bargo, F, Muller, LD, Kolver, ES, Delahoy, JE., 2003. 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.

Baumont, R., Cohen-Salmon, D., Prache, S., Sauvant, D., 2004. A mechanistic model of intake and grazing behavior in sheep integrating sward architecture and animal decisions. Anim. Feed Sci. Tech. 112, 5–28. https://doi.org/10.1016/j.anifeedsci.2003.10.005.

Beauchemin, K.A., 2018. Invited review Current perspectives on eating and rumination activity in dairy cows. J. Dairy Sci. 101, 4762–4784. https://doi.org/10.3168/jds.2017-13706.

Beck, M.R., Gregorini, P., 2020. How dietary diversity enhances hedonic and eudaimonic well-being in grazing ruminants. Front. Vet. Sci. 7, 191. https://doi.org/10.3389/vets 2020 00191.

Bellarby, J., Reyes, T., Leip, A., Weiss, F., Lesschen, J.P., Smith, P., 2013. Livestock greenhouse gas emissions and mitigation potential in Europe. Glob. Chang. Biol. 13, 3–18. https://doi.org/10.1111/j.1365-2486.2012.02786.x.

Berhan, T., Puchala, R., Sahlu, T., Merkell, R.C., Goetsch, A.L., 2005. Effects of length of pasture access on energy use by growing meat goats. J. Appl. Anim. Res. 28, 1–7. https://doi.org/10.1080/09712119.2005.9706778.

Bonanno, A., Di Grigoli, A., Mazza, F., De Pasquale, C., Giosuè, C., Vitale, F., Alabiso, M., 2016. Effects of ewes grazing sulla or ryegrass pasture for different daily durations on forage intake, milk production and fatty acid composition of cheese. Animal 10, 2074–2082. https://doi.org/10.1017/S1751731116001130.

Bott, R.C., Green, E.A., Koch, K., Martinson, K.L., Siciliano, P.D., Williams, C., Trottier, N. L., Burk, A., Swinker, A., 2013. Production and environmental implications of equine grazing. J. Equine Vet. Sci. 33, 1031–1043. https://doi.org/10.1016/j.jevs.2013.05.004.

Buccioni, A., Decandia, M., Minieri, S., Molle, G., Cabiddu, A., 2012. Lipid metabolism in the rumen: New insights on lipolysis and biohydrogenation with an emphasis on the role of endogenous plant factors. Anim. Feed Sci. and Tech. 174, 1–25. https://doi.org/10.1016/j.anifeedsci.2012.02.009.

Burla, J.-B., Ostertag, A., Pratt, A., Bachmann, I., Hillmann, E., 2016. Effects of feeding management and group composition on agonistic behaviour of group-housed horses. Appl. Anim. Behav. Sci. 176, 32–42. https://doi.org/10.1016/j.applanim.2016.01.011.

Cabiddu, A., Addis, M., Fiori, M, Spada, S., Decandia, M., Molle, G., 2017. Pros and cons of the supplementation with oilseed enriched concentrates on milk fatty acid profile of dairy sheep grazing Mediterranean pastures. Small Rumin. Res. 147, 63–72. https://doi.org/10.1016/j.smallrumres.2016.11.019.

Campbell, T.A., Doughty, H., Harris, P.A., de Laat, M.A., Sillence, M.N., 2020. Factors affecting the rate and measurement of feed intake for a cereal-based meal in horses. J. Eq. Vet. Sci. 84 https://doi.org/10.1016/J.jevs.2019.102869.

Cannas, A., Tedeschi, L.O., Molle, G., Atzori, A.S., Dimauro, C, Lunesu, MF, 2016. Prediction of optimal NDF intake in sheep. Can. J. Anim. Sci. 96, 628–629. https://doi.org/10.1139/cjas-2016-0149.

Cannas, A., 2004. Feeding of lactating ewe. editor. In: Pulina, G (Ed.), Dairy Sheep Nutrition, C. AB International, Wallingford, Oxon, UK, pp. 31–49.

Chapinal, N., Goldawk, C., de Passillé, A.M., Keyserlingk, von M.A.G., 2010. Overnight access to pasture does not reduce milk production or feed intake in dairy cattle. Livest. Sci. 129, 104–110. https://doi.org/10.1016/j.livsci.2010.01.011.

Charlton, G.L., Rutter, S.M., 2017. The behaviour of housed dairy cattle with and without pasture access A review. App. Anim. Behav. Sci. 192, 2–9. https://doi.org/10.1016/j.applanim.2017.05.015.

Charpentier, A., Delagarde, R., 2018. Milk production and grazing behavior responses of Alpine dairy goats to access time to pasture or to daily pasture allowance on temperate pastures in spring. Small Rumin Res 162, 48–56. https://doi.org/10.1016/j.smallrumres.2018.03.004.

Charpentier, A., Delagarde, R., 2019. Intake, milk production and grazing behavior responses of strip-grazing dairy goats to daily time to pasture and dehydrated lucerne supplementation. Livest. Sci. 229, 90–97. https://doi.org/10.1016/j.livsci.2019.09.019.

Chavez, S.J., Siciliano, P.D., 2011. Horse intake estimation of AM versus PM grazing. J. Equine Vet. Sci. 31, 230–356. https://doi.org/10.1016/j.jevs.2011.03.123.

Chaya, L., Cowan, E., McGuire, B., 2006. A note on the relationship between time spent in turnout and behaviour during turnout in horses (Equus caballus). Appl. Anim. Behav. Sci. 98, 155–160.

Chen, Y., Luo, H., Wang, Z., Zhang, Y., Liu, K., Jiang, L., Chang, Y., Zuo, Z., 2013. Effect of restricted grazing time on the foraging behavior and movement of Tan sheep grazed on desert steppe. Asian Australas. J. Anim. Sci. 26, 711–715. https://doi.org/10.5713/ajas.2012.12556.

Chilibroste, P., Tamminga, S., Van Bruchem, J., Van der Togt, P.L., 1989. Effect of allowed grazing time, inert rumen bulk and length of starvation before grazing on the weight, composition and fermentative end-products of the rumen contents of lactating dairy cows. Grass Forage Sci 53, 146–156. https://doi.org/10.1046/j.1365-2494.1998.5320146.x.

Chilibroste, P., Soca, P., Mattiauda, D., Bentancur, O., Robinson, P.H., 2007. Short term fasting as a tool to design effective grazing strategies for lactating dairy cattle: a review. Anim. Prod. Sci. 47, 1075–1084. https://doi.org/10.1071/EA0613.

Chilibroste, P., Gibb, M.J., Soca, P., Mattiauda, D.A., 2015. Behavioural adaptation of grazing dairy cows to changes in feeding management: do they follow a predictable pattern. Anim. Prod. Sci. 55, 328–338. https://doi.org/10.1071/AN14484.

Clark, D.E.F., McLeod, K.L.M., Glassey, C.B., Gregorini, P., Costall, D.A., Betteridge, K., Jago, J., 2010. Capturing urine while maintaining pasture intake, milk production, and animal welfare of dairy cows in early and late lactation. J. Dairy Sci. 93, 2280–2286. https://doi.org/10.3168/jds.2009-2907.

Clarke, L.L., Roberts, M.C., Argenzio, R.A., 1990. Feeding and digestive problems in horses. Physiological responses to a concentrate meal. Vet. Clin. North Am. Equine Pract. 6, 433–450. https://doi.org/10.1016/S0749-0739(17) 30550.

Clauss, M., 2013. Digestive physiology and feeding behaviour of equids – a comparative approach. Horse Health Nutrition. European Equine Health Nutrition Congress, Gent, Belgium, pp. 25–33. https://doi.org/10.5167/uzh-76378.

Collas, C., Dumont, B., Delagarde, R., Martin-Rosset, W., Fleurance, G., 2015. Energy supplementation and herbage allowance effects on daily intake in lactating mares. J. Anim. Sci. 93, 2520–2529.

Crump, A., Jenkins, K., Bethell, E.J., Ferris, C.P., Arnott, G., 2019. Pasture Access Affects Behavioral Indicators of Wellbeing in Dairy Cows. Animals 9, 902. https://doi.org/10.3390/ani9110902.

Dall-Orsoletta, A.C., Almeida, J.G.R., Carvalho, P.C.F., Savian, J.V., 2016. Ryegrass pasture combined with partial total mixed ration reduces enteric methane emissions

and maintains the performance of dairy cows during mid to late lactation. J. Dairy Sci. 99, 4374–4383. https://doi.org/10.3168/jds.2015-10396.
Dawkins, M.S, 1990. From an Anmal's point of view Motivation, fitness and animal welfare. Behav. Brain Sci. 13, 1–61.
De Renobales, M., Amores, G., Arranz, J., Virto, M., Barrón, L.J.R., Bustamante, M.A., Ruiz de Gordoa, J.C., Nájera, A.J., Valdivielso, I., Abilleira, E., Beltrán de Heredia, I., Pérez-Elortondo, F.J., Ruiz, R., Abisu, M., Mandaluniz, N., 2012. Part-time grazing improves sheep milk production and its nutritional characteristics. Food Chem 130, 90–96. https://doi.org/10.1016/j.foodchem.2011.07.002.
DeBoer, M.L., Hathaway, M.R., Kuhle, K.J., Weber, P.S.D., Reiter, A.S., Sheaffer, C.C., Wells, S.M., Martinson, K.L., 2018. Glucose and insulin response of horses grazing alfalfa, perennial cool-season grass, and Teff across seasons. J. Equine Vet. Sci. 68, 33–38. https://doi.org/10.1016/j.jevs.2018.04.008.
Delaby, R., Peyraud, J.L., Pérez-Ramirez, E., Delagarde, R., 2008. Effect and carryover effect of spring grazing access time on dairy cow performance. In Hopkins, A., Gustafsson, T., Bertilson, J., Nilsdotter-Linde, N., Spörndly, Editors. Biodiversity and animal Feed, future challenges for grassland production, Grassland Science in Europe 13, 759–761.
Delagarde, R., Peyraud, J.L., Delaby, L., Faverdin, P., 2000. Vertical distribution of biomass, chemical composition, and pepsine-cellulase digestibility in a perennial ryegrass sward interaction with and year, regrowth age and time of day. Anim. Feed. Sci. Tech. 84, 49–68. https://doi.org/10.1016/S0377-8401(00)00114-094.
Delagarde, R., Faverdin, P., Baratte, C., Peyraud, J.L., 2011. GrazeIn a model of herbage intake and milk production for grazing dairy cows. 2. Prediction of intake under rotational and continuously stocked grazing management. Grass Forage Sci 66, 45–60. https://doi.org/10.1111/j.1365-2494.2010.00769.x.
Dewhurst, R.J., Shingfield, K.J., Lee, M.R.F., Scollan, N.D., 2006. Increasing the concentrations of beneficial polyunsaturated fatty acids in milk produced by dairy cows in high-forage systems. Anim. Feed Sci. Tech. 131, 168–206. https://doi.org/10.1016/j.anifeedsci.2006.04.016.
Dillon, P., Crosse, S., O'Brien, B., Mayes, R.W., 2002. The effect of forage type and level of concentrate supplementation on the performance of spring-calving dairy cows in early lactation. Grass Forage Sci. 57, 212–223.
Dobos, R.C., Fulkerson, W.J., Sinclair, K., Hinch, G.N., 2009. Grazing behaviour and pattern of intake of dairy cows grazing kikuyu (Pennisetum clandestinum) grass pastures in relation to sward height and length of grazing session. Anim. Prod. Sci. 49, 233–238. https://doi.org/10.1071/EA08212.
Dohme-Meier, L.D., Kaufmann, S.G., Junghans, P., Metges, C.C., vanDorland, H.A., Bruckmaier, R.M., Münger, A., 2014. Comparison of energy expenditure, eating pattern and physical activity of grazing and zero-grazing dairy cows, at different time points during lactation. Livest. Sci. 162, 86–96. https://doi.org/10.1016/j.livsci.2014.01.006.
Dowler, L.E., Siciliano, P.D., 2009. Prediction of hourly pasture dry matter intake in horses. J. Equine Vet. Sci. 29, 354–355.
Dowler, L.E., Siciliano, P.D., Pratt-Phillips, S.E., Poore, M., 2012. Determination of pasture dry matter intake rates in different seasons and their application in grazing management. J. Equine Vet. Sci. 32, 85–92. https://doi.org/10.1016/j.jevs.2011.06.006.
Durham, A.E., Frank, N., McGowan, C.M., Menzies-Gow, N., Roelfsema, E., Vervuert, I., Feige, K., Fey, K., 2018. ECEIM consensus statement on equine metabolic syndrome. J. Vet. Intern. Med. 33, 335–349. https://doi.org/10.1111/jvim.15423.
Dwyer, C.M., Lawrence, A.B., 2008. Introduction to the animal welfare and the sheep. In: Dowyer, CM (Ed.), The welfare of sheep 1–40.
Eduard, N., Fleurence, G., Martin-Rosset, W., Duncan, P., Dulphi, J.P., Grange, S., Baumont, R., Doubroeucq, H., Pèrez-Barberia, F.J., Gordon, I.J., 2008. Voluntary intake and digestibilities in horses effect of forage quality with emphasis on individual varibility. Animal 2, 1526–1533. https://doi.org/10.1017/S1751731108002760.
Ellis, AD, 2010. Biological basis of behaviour and feed intake in horses. In: Ellis, AD, Longland, A, Coenen, M, Miraglia, N (Eds.), The impact of Nutrition on the Health and Welfare of Horses. Wageningen Academic Publishers, Wageningen, The Netherlands, pp. 53–74. EAAP Publication No. 128.
Erhard, H.W., Davidson, G.C., Elston, D.A., 2001. Can one unrestricted meal buffer the effects of previous pre-meal intervals on the feeding behaviour of sheep. Appl. Anim. Behav. Sci. 71, 217–227. https://doi.org/10.1016/S0168-1591(00)00185-4.
Feillet, C.A., Albrecht, U., Challet, E., 2006. Feeding time for the brain a matter of clock. J. Physiol. Paris 100, 252–260. https://doi.org/10.1016/j.jphysparis.2007.05.002.
Felix, A., Repetto, J.L., Hernandez, N., Perez-Ruchel, A., Cajarville, C., 2017. Restricting the time access to fresh forage reduces intake and energy balance but does not affect digestive utilization of nutrients in beef heifers. Anim. Feed Sci. Tech. 226, 103–112. https://doi.org/10.1016/j.anifeedsci.2017.02.016.
Feng, C., Ding, S., Zhang, T., Li, Z., Wang, D., Wang, L., Liu, C., Sun, J., Peng, F., 2016. High plant diversity stimulates foraging motivation in grazing herbivores. Basic Appl. Ecol. 17, 43–51. https://doi.org/10.1016/j.baae.2015.09.004.
Finocchiaro, R., van Kaaam, J.B.C.H.M., Sardina, M.T., Misztal, I., 2005. Effect of heat stress on production in Mediterranean dairy sheep. Ital. J. Anim. Sci. 4 (2), 70–72. https://doi.org/10.3168/jds.S0022-0302(05)72860-5. Suppl.
Frank, N., Tadros, E.M., 2014. Insulin dysregulation. Equine Vet. J. 46, 103–112.
Frank, N., 2009. Equine metabolic syndrome. J. Equine Vet. Sci. 29, 259–267. https://doi.org/10.1016/j.cveq.2010.12.004.
Freedman, M.S., Lucas, R.J., Sony, B., von Schantz, M., Muñoz, M., David-Gray, Z., Foster, R., 1999. Regulation of Mammalian circadian behavior by non-rod non-cone, ocular photoreceptors. Science 284, 502–504. https://doi.org/10.1126/science.284.5413.502.
Garcia-Rodriguez, A., Oregui, L.M., 2004. Effect of time spent on pasture and protein content of the concentrate on milk yields and body reserves. Grassland Science in Europe 9, 662–664.
Garcia-Rodriguez, A., Mandaluniz, N., Oregui, L.M., 2005. Effect of time spent on pasture on grazing behaviour. In: Proceedings of International Grassland Congress. Dublin. Abs. CD ROM.
Gibb, M.J., Huckle, C.A., Nuthall, R., Rook, A.J., 1999. The effect of physiological state (lactating or dry) and surface height on grazing behaviour and intake by dairy cows. Appl. Anim. Behav. Sci. 63, 269–287.
Ginane, C., Petit, M., 2005. Constraining the time available to graze reinforces heifers' preference for sward of high quality despite low availability. Appl. Anim. Behav. Sci. 94, 1–14. https://doi.org/10.1038/s41598-017-15875-8.
Glunk, E.C., Siciliano, P.D., 2011. Effect of restricted grazing on dry matter intake rate. J. Equine Vet. Sci. 31, 296. Abst.
Glunk, E.C., Pratt-Phillips, S.E., Siciliano, P.D., 2013. Effect of restricted pasture access on pasture dry matter intake rate, dietary energy intake, and fecal pH horses. J. Equine Vet. Sci. 33, 421–426. https://doi.org/10.1016/j.jevs.2012.01.004.
Gregorini, P., Gunter, S.A., Masino, C.A., Beck, P.A., 2007. Effects of ruminal fill on short-term herbage intake rate and grazing dynamics of beef heifers. Grass Forage Sci 62, 346–354.
Gregorini, P., Soder, K.J., Kensinger, R.S., 2009a. Effects of rumen fill on short-term ingestive behaviour and circulating concentrations of ghrelin, insulin, and glucose of dairy cows foraging vegetative micro-swards. J. Dairy Sci. 92, 2095–2105. https://doi.org/10.3168/jds.2008.1803.
Gregorini, P., Clark, C.E.F., Jago, J.C., Glassey, C.B., Mcleod, M., Romars, A.J., 2009b. Restricting time at pasture effects on dairy cow herbage intake, foraging behaviour, hunger-related hormones, and metabolites concentration during the first grazing session. J. Dairy Sci. 92, 4572–4580. https://doi.org/10.3168/jds.2009-2322.
Gregorini, P., Clark, C., McLeod, K., Glassey, C., Romera, A., Jago, J., 2011. Short communication: feeding station behavior of grazing dairy cows in response to restriction of time pasture. Livest. Sci. 137, 287–291. https://doi.org/10.1016/j.livsci.2010.11.017.
Gregorini, P., 2012a. Diurnal grazing pattern its physiological basis and strategic management. Anim. Prod. Sci. 52, 416–430. https://doi.org/10.1071/AN11250.
Gregorini, P., DelaRue, B., McLeod, K., Clark, C.E.F., Glassey, C.B., Jago, J., 2012b. Rumination behaviour of grazing dairy cows in response to restricted time at pasture. Livest. Sci. 146, 95–98. https://doi.org/10.1016/j.livsci.2012.02.020.
Gregorini, P., Beukes, P.C., Romera, A.J., Levya, G., Hanigan, M.B., 2013. A model of diurnal grazing patterns and herbage intake of a dairy cow. MINDY Model description. Ecol. Model. 270, 11–29. https://doi.org/10.1016/j.ecolmodel.2013.09.001.
Gregorini, P., Waghorn, G.C., Kuhn-Sherlock, B., Romera, A.J., Macdonald, K.A., 2015. Short communication Grazing pattern of dairy cows that were selected for divergent residual feed intake as calves. J. Dairy Sci 98, 6486–6491. https://doi.org/10.3168/jds.2015-9614.
Gregorini, P, Villalba, J.J., Chilibroste, P., Provenza, F.D., 2017. Grazing management setting the table, designing the menu and influencing the diner. Anim Prod. Sci. 57, 1248–1268. https://doi.org/10.1071/AN16637.
Grieveldinger, L., Veissier, I., Boissy, A., 2011. The ability of lambs to form expectations and the emotional consequences of a discrepancy from their expectations. Psychoneuroendocrinology 36, 806–815. https://doi.org/10.1016/j.psyneuen.2010.11.002.
Görgülü, M., Bǒga, M., Şahin, A., Serbester, U., Kutlu, H.R., Şahinler, S., 2008. Diet selection and eating behaviour of lactating goats subjected to time restricted feeding in choice and single feeding system. Small Rumin Res 78, 41–47. https://doi.org/10.1016/j.smallrumres.2008.04.004.
Harris, P.A., Ellis, D.A., Fradinho, M.J., Jansson, A., Julliand, V., Luthersson, N., Santos, A.S., Vervuert, I., 2017. Review Feeding conserved forage to horses recent advances and recommendations. Animal 11 (6), 958–967. https://doi.org/10.1017/S1751731116002469, 2017.
Harris, P.A., 2007. Impact of nutrition and feeding practices on equines, their behaviour and welfare. In: Hausberger, M, Søndergaard, E., Martin-Rosset, W. (Eds.), Horse behaviour and welfare. EAAP, pp. 99–113. Publication No. 122.
Hassoun, P., 2002. Cattle feeding behaviour at pasture: a methodology related to on farm measurements. Anim. Res. 51, 35–41. https://doi.org/10.1051/animres2002005, 2002.
Hernandez-Mendo, O., Leaver, J.D., 2004. Effect of replacing time available for grazing with time available for eating maize silage and soyabean meal on milk yield and feeding behaviour. Grass Forage Sci 59, 318–330. https://doi.org/10.1111/j.1365-2494.2004.00434.x.
Herzog, E.D., Muglia, L.J., 2006. You are when you eat. Nature Neurosci 9, 300–302.
Hodgson, J., 1990. Grazing management science into practice. Longman Group, Burnt Mill, Harlow, UK, p. 203.
Hothresall, B., Casey, R., 2012. Undesired behaviour in horses a review on their development, prevention, management and association with welfare. Equine Vet. Educ. 24, 479–485. https://doi.org/10.1111/J.2042-3292.2011.00296.x.
Iason, G.R., Mantecon, A.R., Sim, D.A., Gonzalez, J., Foreman, E., Bermudez, F.F., Elston, D.A., 1999. Can grazing sheep compensate for a daily foraging time constraint. J. Anim. Ecol. 68, 87–93.
Jung, H.G., Rice, R.W., Koong, L.J., 1985. Comparison of heifer weight gains and forage quality for continuous and short duration grazing systems. J Range Manag 38, 144–148. https://doi.org/10.2307/3899258.
Keli, A., Ribeiro, L.P.S., Gipson, T.A., Puchala, R., Tesfai, K., Tsukahara, Y., Sahlu, T., Goetsch, A.L., 2017. Effect of pasture access regime on performance, grazing behavior, and energy utilization by Alpine goats in early and mid-lactation. Small Rumin Res 54, 58–69. https://doi.org/10.1016/j.smallrumres.2017.07.004.

Kennedy, E., McEvoy, M., Murphy, J.P., O'Donovan, M., 2009. Effect of restricted acess time to pasture on dairy cow milk production, grazing behavior, and dry matter intake. J. Dairy Sci. 92, 168–176. https://doi.org/10.3168/jds.2008-1091.
Kennedy, E., Curran, J., Mayes B., McEvoy, M., Murphy, J.P., O'Donovan, M., 2011. Restricting dairy cow access time to pasture in early lactation: the effects on milk production, grazing behaviour and dry matter intake. Animal 511, 1805-1813. doi 10.1017/S1751731111000826.
Kismul, H., Spörndly, E., Höglind, M., Næss, G., Eriksson, T., 2018. Morning and evening pasture access – comparing the effect of production pasture and exercise pasture on milk production and cow behaviour in an automatic milking system. Livest. Sci. 217, 44–54. https://doi.org/10.1016/j.livsci.2018.09.013.
Kismul, H., Spörndly, E., Höglind, M., Eriksson, T., 2019. Nighttime pasture access comparing the effect of production pasture and exercise paddock on milk production and cow behaviour in an automatic milking system. J. Dairy Sci. 102, 10423–10438. https://doi.org/10.3168/jds.2019.16416.
Knowles, S.Q., Grace, N.D., 2013. A recent assessment of the elemental composition of New Zealand pastures in relation to meeting the dietary requirements of grazing livestock. J. Anim. Sci. 92, 303–310. https://doi.org/10.2527/jas.2013-6847.
Ko, C.H., Takahashi, J.S., 2006. Molecular components of the mammalian circadian clock. Hum. Mol. Genet. 15 (2), 271–277. https://doi.org/10.1093/hmg/ddl207. Spec No.
Kristensen, T., Oudshoorn, F., Munskgaard, L., Søegaard, K., 2007. Effect of time at pasture combined with restricted indoor feeding on production and behaviour in dairy cows. Animal 1, 439–448. https://doi.org/10.1017/S1751731107694117.
Laca, E.A., Ungar, E.D., Denment, M.W., 1994. Mechanisms of handling time and intake rate of a larhe mammalian grazer. Appl. Anim. Behav. Sci. 39, 3–19. https://doi.org/10.1016/0168-1591(94)90011-6.
Landau, S.Y., Provenza, F., 2020. Of browse, goats, and men Contribution to the debate on animal traditions and cultures. Appl. Anim. Behav. Sci. 232, 105–127. https://doi.org/10.1016/j.applanim.2020.105127.
Laporte, I., Muhly, T.B., Pitt, J.A., Alexander, M., Musiani, M., 2010. Effects of wolves on elk and cattle behaviors implications for livestock production and wolf conservation. PLoS ONE 5 (8), e11954. https://doi.org/10.1371/journal.pone.0011954.
Longland, A.C., Byrdy, B.M., 2006. Pasture Nonstructural Carbohydrates and Equine Laminitis. The J. Nutr. Supplement 2099S–2102S. https://doi.org/10.1093/jn/136.7.2099S.
Longland, A.C., Barfoot, C., Harris, P.A., 2016. Effects of grazing muzzles on intakes of dry matter and water soluble carbohydrates by ponies grazing spring, summer, and autumn swards as well as autumn swards of different heights. J. Equine Vet. Sci. 40, 26–33.
Mattiauda, D.A., Tamminga, S., Gibb, M.J., Soca, P., Bentancur, O., Chilibroste, P., 2013. Restricting access time at pasture and time of grazing allocation for Holstein dairy cows ingestive behaviour, dry matter intake and milk production. Livest. Sci. 152, 53–62. https://doi.org/10.1016/j.livsci.2012.12.010.
Mayes, E., Duncan, P., 1986. Temporal patterns of feeding behavior in free-ranging horses. Behaviour 96, 105–129. https://doi.org/10.1163/156853986×00243.
McGreevy, P.J., Cripps, N., French, P., Green, L.E., Nicol, C.J., 1995. Management factors associated with stereotypic and redirected behaviour in the Thoroughbred horse. Equine Vet. J. 27, 86–91.
Meijer, J.H., Rietveld, W.J, 1989. Neurophysiology of the SCN circadian pacemaker in rodents. Physiol. Rev. 69, 671–707. https://doi.org/10.1152/physrev.1989.69.3.671.
Mistleberger, R.E., 2004. Circadian food-anticipatory activity formal models and physiological mechanisms. Neurosci. and Behav. R. 18, 171–195. https://doi.org/10.1016/0149-7634(94)90023-x.
Molle, G., Branca, A., Ligios, S., Sitzia, M., Casu, S., Landau, S., Zoref, Z., 1995. Effect of grazing background and flushing supplementation on reproductive performance in Sarda ewes. Small Rumin. Res. 17, 245–254. https://doi.org/10.1016/0921-4488(95)00691-D.
Molle, G., Decandia, M., Cabiddu, A., Landau, S.Y., Cannas, A., 2008. An update on the nutrition of dairy sheep grazing Mediterranean pastures. Small Rumin. Res. 77, 93–112. https://doi.org/10.1016/j.smallrumres.2008.03.003.
Molle, G., Decandia, M., Giovanetti, V., Cabiddu, A., Fois, N., Sitzia, M., 2009. Responses to condensed tannins of flowering sulla (Hedysarum coronarium L.) grazed by dairy sheep. Part 1 Effects on feeding behaviour, intake, diet digestibility and performance. Livest. Sci. 123, 138–146. https://doi.org/10.1016/j.livsci.2008.11.018.
Molle, G., Decandia, M., Giovanetti, V., Manca, C., Acciaro, M., Epifani, G., Salis, L., Cabiddu, A., Sitzia, M., Cannas, A., 2014a. Effects of restricted time allocation to pasture on feeding behaviour, intake and milk production of dairy sheep rotationally grazing Italian ryegrass (Lolium multiflorum Lam) in spring. Anim. Prod. Sci. 54, 1233–1237. https://doi.org/10.1071/AN14376.
Molle, G., Giovanetti, V., Decandia, M., Sitzia, M., Atzori, A.S., Cannas, A., 2014b. Modelling herbage intake of part-time grazing dairy sheep. In Harper KJ, McNeill DM, Bell AW, editors. Program and Abstracts of the Eight International Workshop on Modelling Nutrient Digestion and Utilization in Farm Animals, 15-17 September 2014, Cairns, North Queensland, Australia, p. 69.
Molle, G., Decandia, M., Giovanetti, V., Manca, C., Acciaro, M., Epifani, G., Salis, L., Cabiddu, A., Cannas, A., Sitzia, M., 2016. The timing of access to pasture affects ingestive behaviour and milk yield of dairy ewes. Grassland Science in Europe 21, 415–417.
Molle, G., Decandia, M., Giovanetti, V., Manca, C., Acciaro, M., Epifani, G., Salis, L., Cabiddu, A., Sitzia, M., Cannas, A., 2017. Grazing behaviour, intake and performance of dairy ewes with restricted access time to berseem clover (Trifolium alexandrinum L.) pasture. Grass Forage Sci 72, 194–210. https://doi.org/10.1111/gfs.12228.
Molle, G., Decandia, M., Giovanetti, V., Manca, C., Acciaro, M., Cossu, R., Serra, M.G., Salis, L., Cabiddu, A., Sitzia, M., 2018. Grazing behaviour of dairy ewes as affected by spatial and time allocation of forage crops. Grassland Science in Europe 23, 301–303.
Molle, G., 2014. PhD thesis. University of Sassari, Sassari, Italy.
Murphy, B.A., 2019. Circadian and circannual regulation in the horse internal timing in an elite athlete. J. Equine Vet. Sci. 76, 14–24. https://doi.org/10.1016/j.jevs.2019.02.026.
National Equine Welfare Council, 2015. file:///C:/Users/Utente/Downloads/NEWC%20Grazing%20Muzzle%20%20download%20final%20002.pdf Accessed on March 26, 2022.
Orr, R.J., Penning, P.D., Harvey, A., Champion, R.A., 1997. Diurnal patterns of intake rate by sheep grazing monocultures of ryegrass or white clover. Appl. Anim. Behav. Sci. 52, 65–77. https://doi.org/10.1016/S0168-1591(96)01120-3.
Penning, P.D., Parsons, A.J., Newman, J.A., Orr, R.J., Harvey, A., 1993. The effects of group size on grazing tume in sheep. Appl. Anim. Behav. Sci. 37, 101–109.
Penning, P.D., 1986. Some effects of sward conditions on grazing behavior and intake by sheep. In Gudmunsson O., editor. Grazing Research at Northern Latitudes NATO ASI Serie A Life Sciences, 108, 219–226.
Perez-Ramirez, E., Delagarde, R., Delaby, L., 2008. Herbage intake and behavioural adaptation of grazing dairy cows by restricting time at pasture under two feeding regimes. Animal 2, 1384–1392. https://doi.org/10.1017/S17551731108002486.
Perez-Ramirez, E., Pyraud, J.L., Delagarde, R., 2009. Restricting daily time at pasture at low and high pasture allowance effects on pasture intake and behavioural adaptation of lactating dairy cows. J. Dairy Sci. 92, 3331–3340. https://doi.org/10.3168/jds.2008-1951.
Perez-Ruchel, A., Repetto, J.L., Cajarville, C., 2013. Suitability of live yeast addition to alleviate the adverse effects due to the restriction of the time of access to feed in sheep fed only pasture. J. Anim. Physiol. Anim. Nutr. (Berl) 97, 1043–1050. https://doi.org/10.1111/jpn.12008.
Perojo, A., Garcia-Rodriguez, A., Arranz, J., Oregui, L.M., 2005. Effects of time spent on pasture on milk yield, body reserves, herbage intake and grazing behaviour. In Molina Alcaide E. (ed.), Ben Salem H. (ed.), Biala K. (ed.), Morand-Fehr P. (ed.). Sustainable grazing, nutritional utilization and quality of sheep and goat products. Options Méditerranéennes Série A. Séminaires Méditerranéens; n. 67, 275-279.
Piccione, G., Caola, G., Refinetti, R., 2003. Circadian rhythms of body temperature and liver function in fed and food-deprived goats. Comp. Biochem. Phys. Part A 134, 563–572. https://doi.org/10.1016/S1095-6433(02)00362-8.
Porcu, C., Rodriguez, A., Dattena, M., Gallus, M., Pilichi, S., Molle, G., 2014. Studio preliminare sull\'effetto residuo di un pascolamento razionato in pecore sottoposte a effetto, maschio e flushing con lupino. In: Proc. of XXI congress of SIPAOC, Large Anim. Rev., p. 149, 2014Supp.
Provenza, F.D., Kronberg, S.L., Gregorini, P., 2019. Is Grassfed Meat and Dairy Better for Human and Environmental Health. Front. Nutr. 6, 26, 12.
Provenza, F.D., Meuret, M., Gregorini, P., 2015. Our landscapes, our livestock, ourselves Restoring broken linkages among plants, herbivores, and humans with diets that nourish and satiate. Appetite 95, 500–519. https://doi.org/10.1016/j.appet.2015.08.004.
Pulina, G., Avondo, M., Molle, G., Dias, Francesconi, A.H., Atzori, A.S., Cannas, A., 2013. Models for estimating feed intake in small ruminants. Rev. Brasileira de Zootecnia 42, 675–690. https://doi.org/10.1590/S1516-35982013000900010.
Rego, O.A., Regalo, S.M.M., Rosa, H.J.D., Alves, S.P., Borba, A.E.S., Bessa, R.J.B., Cabrita, A.R.J., Fonseca, A.J.M., 2008. Effects of grass silage and soybean meal supplementation on milk production and milk fatty acid profiles of grazing dairy cows. J. Dairy Sci. 91, 2736–2743. https://doi.org/10.3168/jds.2007–0786.
Riaz, M.Q., K, H, Clauss, M., Jayanegara, A., 2014. Voluntary feeding intake and digestibility of four domestic ruminant species as influenced by dietary constituents. A meta-analysis. Livest. Sci. 162, 76–85. https://doi.org/10.1016/j.livsci.2014.01.009.
Rivera, E., Benjamin, S., Nielsen, B., Shelle, J., Zanella, A.J., 2002. Behavioural and physiological responses of horses to initial training the comparison between pastured versus stalled horses. Appl. Anim. Behav. Sci. 78, 235–252.
Rochais, C., Henry, S., Hausberger, M., 2018. Hay-bags" and "slow feeders" testing their impact on horse behaviour and welfare. Appl. Anim. Behav. Sci. 198, 52–59. https://doi.org/10.1016/j.applanim.2017.09.019.
Sairanen, A., Khalili, H., Virkajärvi, P., Hakosalo, J., 2006. Comparison of part-time grazing and indoor silage feeding on milk production. Agric. Food Sci. 15, 280–292.
Santana, A., Cajarville, C., Mendoza, A., Repetto, J.L., 2017. Combination of legume-based herbage and total mixed ration (TMR) mantains intake and nutrient utilization of TMR and improves nitrogen utilization of herbage in heifers. Animal 11, 616–624. https://doi.org/10.1017/S17517311160011956.
Schmitz, A., Tonn, B., Schöppner, A.-K., Isselstein, J., 2020. Using a citizen science approach with German horse owners to study the locomotion behaviour of horses on pasture. Sustainability 12, 1835. https://doi.org/10.3390/su12051835.
Shalloo, L., Dillon, P., O'Loughlin, J., Rath, M., Wallace, M., 2004. Comparison of a pasture-based system of milk production on a high rainfall, heavy-clay soil with that on a lower rainfall, free-draining soil. Grass Forage Sci 59, 157–168. https://doi.org/10.1111/j.1365-2494.2004.00415.x.
Shipley, L., Gross, J.E., Spalinger, D.E., Thompson, Hobbs, N., 1994. Am. Nat. 143, 1055–1082.
Shrader, A.M., Kerley, G.I.H., Kotler, B.P., Brown, J.S., 2007. Social information, social feeding, and competition in group-living goats (Capra hircus). Behav. Ecol. 18, 103–107.
Siciliano, P.D., Schmitt, S., 2012. Effect of restricted grazing on hindgut pH and fluid balance. J. Equine Vet. Sci. 32, 558–561. https://doi.org/10.1016/j.jevs.2012.01.004.

Siciliano, P., 2012. Estimation of pasture dry matter intake and its practical application in grazing management for horses. In: Zimmermann, N.G. (Ed.), Proc. of the 10th Annual Mid-Atlantic Nutrition Conference. University of Maryland, College Park, MD, pp. 9–12, 20742.

Siciliano, P.D., Gill, J.C., Bowman, M.A., 2017. Effect of sward height on pasture nonstructural carbohydrate concentrations and blood glucose/insulin profiles in grazing horses. J. Equine Vet. Sci. 57, 29–34. https://doi.org/10.1016/j.jevs.2017.06.004.

Silva, N.C.D., Puchala, R., Gipson, T.A., Sahlu, T., Goetsch, A,L., 2018. Effect of restricted periods of feed access on feed intake, digestion, behaviour, heat energy, and performance of Alpine goats. J. Appl. Res. 46, 994–1003. https://doi.org/10.1080/09712119.2018.1450259.

Smith, D.G., Cuddeford, D., Pearson, R.A., 2006. The effect of extended grazing time and supplementary forage on the dry matter intake and foraging behaviour of cattle kept under traditional African grazing systems. Trop, Anim. Health Prod. 38, 75–84. https://doi.org/10.1007/s11250-006-4342-3.

Stephenson, H.M., Green, M.J., Freeman, S.L., 2011. Prevalence of obesity in a population of horses in the UK. Vet. Rec. 168, 131. https://doi.org/10.1136/vr.c6281.

Stokkan, K.A., Yamazaki, S., Tei, H., Sakaki, Y., Menaker, M., 2001. Entrainment of the circadian clock in the liver by feeding. Science 291, 490–493. https://doi.org/10.1126/science.291.5503.490.

Taweel, H.Z., Tas, B.M., Tamminga, S., Dijkstra, J., 2006. The role of rumen fill in terminating grazing bouts of dairy cows under continuous stocking. In: Kebreab, E, Dijkstra, J, Bannink, A, Gerrits, WJJ, France, J (Eds.), Nutrient digestion and utilization in farm animals modelling approaches, pp. 48–53.

Tedeschi, L.O., Molle, G., Menendez, H.M., Cannas, A., Fonseca, M.A., 2019. The assessment of supplementation requirements of grazing ruminants using nutrition models. Transl. Anim. Sci. 3, 812–828. https://doi.org/10.1093/tas/txy140.

Thorne, J.B., Goodwin, D., Kennedy, M.J., Davidson, H.P.B., Harris, P., 2005. Foraging enrichment for individually housed horses. Practicality and effects on behaviour. Appl. Anim. Behav. Sci. 94, 149–164.

Trovar-Luna, I., Puchala, R., Gipson, T.A., Detweiler, G.D., Dawson, L.J., Sahlu, T., Keli, A., Goetsch, A.L., 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. 140, 225–245. https://doi.org/10.1016/j.livsci.2011.03.034.

Ungar, E.D., 1996. Ingestive behaviour. In: Hodgson, J, Illius, AW (Eds.), The ecology and management of grazing systems. CAB International, Wallingford, Oxon, UK, pp. 185–218.

Valenti, B., Priolo, A., Luciano, G., Biondi, L., Scerra, M., Pagano, R.I., Lanza, M., Avondo, M., 2014. Effetto dell'orario di pascolamento sulle performance produttive e sulla qualità della carne di agnello. In: Proc. of XXI Congress of SIPAOC, Large Anim. Rev., p. 163. Supp.

Valenti, B., Marletta, D., De Angelis, A., Di Paola, F., Bordonaro, S., Avondo, M., 2017. Herbage intake and milk yield in Comisana ewes as effect of 4 vs7 h of grazing during late lactation. Trop. Anim. Health Prod. 49, 989–994. https://doi.org/10.1007/s11250-017-1287-7.

Van Soest, P.J., 1994. Nutritional ecology of the ruminant, 2nd Edition. Cornell University Press, Ithaca and London, p. 476.

Weinert-Nelson, J.R., Meyer, W.A., Williams, C.A., 2022. Diurnal variation in forage nutrient composition of mixed cool-season grass, crabgrass, and Bermuda pastures. J. Equine Vet. Sci. 110, 103836 https://doi.org/10.1016/jevs.2021.103836.

Williams, Y.J., Doyle, P.T., Egan, A.R., 2014. Diurnal variation in rumen fill of dairy cows grazing Persian clover at different pasture allowances. Anim. Prod. Sci. 54, 1388–1393. https://doi.org/10.1071/AN14307.

Zhang, X.Q., Luo, H.L., Hou, X.Y., Badgery, W.B., Zhang, Y.J., Jiang, C., 2014. Effect of restricted time at pasture and indoor supplementation on ingestive behavior, dry matter intake and weight gain of growing lambs. Livest. Sci. 167, 137–143. https://doi.org/10.1016/j.livsci.2014.06.001.

Zhang, X., Jin, Y.M., Badgery, W.B., Tana, 2017. Diet selection and n-3 polyinsaturated fatty acid deposition in lambs as affected by restricted time at pasture. Nature Sci. Rep. 7, 15641. https://doi.org/10.1038/s41598-017-15875-8.