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# Seasonal hogget grazing as a potential alternative grazing system for the Qinghai-Tibetan plateau: weight gain and animal behaviour under continuous or rotational grazing at high or low stocking rates

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**Abstract.** The traditional transhumance grazing system on the Qinghai-Tibetan Plateau (QTP) is being replaced by a system in which pastoralists are allocated fixed areas for grazing. In this context, we conducted experiments to evaluate a possible change to seasonal grazing of young animals for weight gain, and the effects of grazing management (continuous grazing (CG) vs rotational grazing (RG)) and stocking rate (SR) on the performance and behaviour of *Oura*-type Tibetan sheep. In Experiment 1 (June–December 2014), 72 Tibetan sheep (initial bodyweight (BW) 32.2 ± 3.37 kg) were allocated to one of three treatments: (1) CG24 – eight sheep grazed continuously in a single 2-ha plot for the entire duration of the experiment; (2) RG24 – eight sheep grazed in a 1-ha plot from June to September (growing season), and then moved to a new plot for September–December grazing (early cold season); (3) RG48 – eight sheep grazed in a 0.5-ha plot, but otherwise as for RG24. All treatments had three replicates. In Experiment 2 (September–December 2014), 48 Tibetan sheep (initial BW 46.3 ± 1.62 kg) were used to repeat the RG24 and RG48 treatments imposed in the early cold season of the Experiment 1. In both experiments, increasing SR significantly reduced bodyweight gain (BWG) per head and increased BWG per ha in the RG treatments. In Experiment 1, RG, compared with CG, did not significantly affect BWG per head, BWG per ha, or feed utilisation efficiency. In both experiments weight gain was small or negative in the early cold season. These results indicate that removal of sheep at the onset of the cold season will be important for retention of the weight gain achieved in the growing season but choice between a CG and RG grazing system is unimportant for the production efficiency in the proposed grazing system of Tibetan sheep.

**Additional keywords:** feed intake, production efficiency, seasonal grazing, stocking rate, Tibetan sheep.

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## Introduction

The Qinghai-Tibetan Plateau (QTP), commonly referred to as the 'Roof of the world', is the highest and largest alpine region in the world. Its unique vegetation and climate are mainly due to its high average altitude of over 4000 m (Shang *et al*. 2014). One of the main types of grassland ecosystem is alpine meadow, which is widely distributed in the mid-eastern part of the QTP and its surrounding mountains (Yuan and Hou 2015). This meadow covers ~$6.37 \times 10^5$ $km^2$ and represents an estimated 25% of the area of the QTP (Kato *et al*. 2006).

The harsh cold season on the QTP has been traditionally dealt with by a system of transhumance and altitudinal migration (Hou *et al*. 2016), a grazing system that originated more than a thousand years ago (Hou *et al*. 2008). Now, some pastoralists on the QTP are given fixed land allocations and so traditional altitudinal migration is gradually being replaced by geographic movement. The Tibetan sheep (*Oura*-type) is one of the major livestock species in the region, with a population of over 50 million on the QTP. Tibetan sheep provide meat and income for local herders (Zhang *et al*. 2014). The sheep graze the whole year round under the traditional transhumance and altitudinal migration farming systems with little supplementation during the harsh cold season (Sun *et al*. 2015). Their productivity fluctuates with the change in the quality and quantity of forage during the year. Pasture growth occurs from May with the peak in grass biomass and quality in the growing season (June–August), followed by a rapid decline in pasture growth and feed value in early autumn. From late autumn until spring (October–May, dry season), there is typically snow cover and only standing dormant grass is available for grazing. As the quality and quantity of available feed progressively declines during the cold season, Tibetan sheep suffer from inadequate feed supply and can lose as much as 20–30% of their pre-cold season bodyweight (Ren *et al*. 2008). In recent decades, herders have tended to increase their herd sizes to meet their economic needs, with the consequence of overgrazing and rangeland degradation (Wu *et al*. 2015). This trend has intensified throughout the past decade, leading to widespread degradation that is partly evidenced by a decrease in the soil carbon content under increased grazing pressure (Yuan and Hou 2015).

The change from a transhumance system to fixed land allocations for grazing on the QTP has resulted in environmental damage from livestock grazing. Although the degradation of rangelands directly affects the livelihoods, food security, and way of life of local farmers (Harris *et al*. 2016), few quantitative grazing studies have been conducted to investigate how to improve the productivity of rangeland and livestock and maintain sustainable development on fixed land for individuals. There is a need to develop new farming systems on the QTP that are sustainable in the harsh environment there. In several countries internationally, for example, in New Zealand, pasture systems have evolved a pattern of sale and purchase of animals between pastoralists in neighbouring regions with different seasonal growth patterns to facilitate movement of animals in a way that optimises feed utilisation across the neighbouring regions. One aim of this study, therefore, was to evaluate the performance of Tibetan sheep when fed QTP alpine meadow pasture, under two different grazing regimes. Specifically, the experiment included a low-input (human and material resources) continuous grazing (CG) and more intensive rotational grazing (RG) system at two different stocking rates (SR) during the growing season. Although it would not be expected that pastoralists would attempt to increase animal bodyweight in the cold season, it was also of interest to investigate how well animal bodyweight attained in the growing season could be held during the cold season, as doing so could potentially spread sale dates over a wider part of the calendar year.

Considering the above, the specific aims of this study were: (i) to investigate the potential meat production per ha in a pastoral system where hoggets are imported for the growing season, testing CG (with a stocking rate chosen to be sustainable under the herbage production expected on the QTP in the growing season), a RG system at the same SR, and a RG system at double the SR; (ii) to investigate the possibility of holding animals grazed in this way, to meet market demands for meat at specific times (e.g. Chinese new year); and (iii) to collect data on animal behaviour in these systems so that this information is available for planning calculations if and when such systems are refined for commercial implementation. The ultimate aim of this research was to provide data that allow sustainable animal production levels for the alpine meadow vegetation on the QTP to be determined, so facilitating sustainable use of the rangeland resources in this region. With respect to SR and grazing regime, Yuan and Hou (2015) estimated for another site in the region that herbage removed by grazing on an annual basis ranged between 0.5 and 1.1 t. DM ha$^{-1}$ year$^{-1}$. At an estimated intake of 1 kg per head per day for animals used in this experiment, 8 sheep ha$^{-1}$ grazing for 3 months (91 days) would consume 728 kg ha$^{-1}$ in a season, and this was the basis for our experimental design. Our chosen stocking rates designated CG24 or RG24, and RG48 denote 24 or 48 sheep months ha$^{-1}$ season$^{-1}$ (SM ha$^{-1}$, respectively). We hypothesised that a SR of 24 SM ha$^{-1}$ would be more sustainable under RG than CG and that compared with 24 SM ha$^{-1}$, 48 SM ha$^{-1}$ would increase meat production per ha but may compromise sustainability of the system.

## Materials and methods

### Conditions at the study site

The two experiments were conducted from 15 June to 15 December 2014 at an experimental pasture farm in Maqu County, Gansu Province, China (Eastern Qinghai-Tibetan Plateau; 33°43′N, 101°44′E; 3600 m a.s.l.). Monthly average temperature ranges from a high of 10−15°C in July and August to below −5°C in December and January; mean annual precipitation (1967–2012) was 605 mm, of which some two-thirds typically falls in the months May–August. The average annual precipitation and temperature at the experiment site over the last 10 years were 608 mm and 2.6°C, respectively. April is typically the first month of the year with a mean average temperature above 0°C. For the months of November–March, much of the landscape has snow cover, and the only fodder for grazing animals is the standing residual dead herbage from the growing season. The average annual precipitation and temperature for the growing season (June–mid-September) season were 345 mm and 11.2°C, respectively. Corresponding values for the early cold season (mid-September–mid-December) were 99 mm and 0.2°C, respectively. In 2014, the total precipitation was 375 mm in the growing season and 55 mm in the early cold season, and the corresponding average temperatures were 10.8°C and 0.6°C respectively. The site has average annual sunshine of 2580 h and more than 270 frost days per year (Ma *et al*. 2013). The soil at the study site is dark black in colour as a result of transformation of plant material to humus in the cold climate and was indicated by Yuan and Hou (2015) to be classified as a Mollisol under the USDA soil taxonomy system. The plots used in the two experiments were selected to be visually identical to and at the same elevation as alpine meadow pastures used by local pastoralists. There was no obvious difference between plots in standing biomass at the start of the experiments. Botanically, the plant community at the site was dominated by Cyperaceae (especially *Kobresia graminifolia* C.B.Clarke) with some Poaceae (*Agrostis matsumurae* Hack. ex Honda, *Festuca elata* Keng ex. E.B.Alexeev, and *Poa annua* L.). Various dicots are also present, including among others, members of the *Asteraceae*, *Fabaceae*, *Polygonaceae*, *Gentianaceae*, and *Ranunculaceae* (Sun *et al*. 2015).

### Experiment design

Experiment 1 was designed to evaluate the effects of grazing management (CG vs RG) and SR [low (24 sheep months ha$^{-1}$, SM ha$^{-1}$) vs high (48 sheep months ha$^{-1}$, SM ha$^{-1}$)] on Tibetan sheep performance and behaviour. The RG system pastures and CG system pastures were adjacent. A total of 72 Tibetan sheep (~12 months old according to the records of pastoralists, BW 32.2 ± 3.37 kg) were used in a three-treatment experiment (three replicates treatment$^{-1}$, giving a total of nine self-contained grazing cells with an eight sheep cell$^{-1}$). The three treatments were as follows: (1) CG24-eight sheep grazed continuously in a single 2-ha plot for the entire duration of the experiment from 15 June to 15 December; (2) RG24-eight sheep grazed in a 1-ha plot from 15 June to 15 September (growing season, 92 days, 24 SM ha$^{-1}$) and then moved to a new plot from 16 September to 15 December grazing (early cold season, 91 days); (3) RG48-eight sheep grazed in a 0.5-ha plot, but otherwise as for RG24 (48 SM ha$^{-1}$). All treatments had three replicates. In Experiment 2 (September–December 2014), 48 Tibetan sheep (initial BW 46.3 ± 1.62 kg) were used to repeat the RG24 and RG48 treatments imposed in early cold season of the Experiment 1. The experimental design is summarised in Table 1.

Experiment 2 was designed to evaluate the effects of low SR (RG24-24 SM ha$^{-1}$) versus high SR (RG48-48 SM ha$^{-1}$) in a RG system with early cold season for 3 months (16 September–15 December). The site of Experiment 2 was located several hundred metres away from that used for Experiment 1, but on land visually matching in soil and vegetation type. In total, 48 Tibetan sheep (~15 months old, BW 46.3 ± 1.62 kg) were subjected to two treatments (three replicates treatment$^{-1}$): (1) RG24-eight sheep grazed in a 1-ha pasture plot for 3 months in the early cold season; (2) RG48–eight sheep grazed in a 0.5-ha early cold season pasture plot for 3 months (Table 1). The early cold season pastures were not grazed during the growing season. The animals were divided into eight blocks of six sheep according to BW (randomised block design) and each of the six animals was assigned, using a random numbers table, to one of the six plots.

Within each replicate of the RG treatments in Experiment 1, each paddock was subdivided into three sub-paddocks, and sheep were rotated among sub-paddocks every 30 days, with 10 days grazing in each sub-paddock followed by a 20-day spell from grazing. For the early cold season pasture, each paddock was subdivided into two sub-paddocks, with 15 days grazing of each, followed by a 15-day spell from grazing. For the CG plots sheep were grazed continuously on a single paddock for 6 months (growing season and early cold season). Before the commencement of these experiments, the pasture had been used in grazing management research for 3 years. All animals were housed indoors during night and grazed on the pasture from 0700 hours to 1900 hours in the growing season and from 0900 hours to 1800 hours in the early cold season. No supplemental feed was offered. There was an adaptation period of 15 days to allow animals to become accustomed to the daily management and routines of the two experiments. For 2 weeks before the adaptation period, the animals grazed on a similar sward and as a single group. Different animals were used in Experiment 1 and Experiment 2.

### *Animal bodyweight*

The animals were weighed individually at the start of the study and then monthly during the study, with a final weighting at the close of the experiment.

### *Recording of animal behaviour*

Six sheep per paddock were randomly selected using a random numbers table and marked with a coloured ribbon for grazing behaviour observations. The grazing period was 12 h in the growing season and 9 h in the early cold season and during grazing, foraging activity of the animals was recorded by trained observers with telescopes. Observers were located at least 10 m away from the sheep. The behaviour of each marked animal was recorded for 10 min, three times per h, giving 36 daily records sheep$^{-1}$ in the growing season and 27 daily records sheep$^{-1}$ in the early cold season. The activities recorded (Hou *et al*. 2003; Baumont *et al*. 2004) were as follows: daily intake time (min daylight$^{-1}$), daily ruminating time (min daylight$^{-1}$), intake rate (bites min$^{-1}$), walking velocity while eating (steps min$^{-1}$), number of steps/daylight, number of chews per bolus, chewing time per bolus (s), and interval between two consecutive boluses during ruminating (s).

### *Metabolisable energy intake*

The metabolisable energy intake (MEI) for individual sheep was calculated as a sum of ME requirements for maintenance and ME for BWG ($ME_g$) using Eqn 1 (AFRC 1993):

$$\mathrm{MEI}\ (\mathrm{MJ\ head^{-1}\ day^{-1}}) = k_1 BW^{0.75} + ME_g BWG \qquad (1)$$

where $k_1$ is a constant for ME requirement for maintenance per kg of metabolic BW, $ME_g$ is the amount of ME required to gain 1 kg

**Table 1. Experimental design**

| Treatment[A] | No. of replicates | No. of sheep replicate$^{-1}$ | Growing season (3 months) Paddock area (ha replicate$^{-1}$) | Growing season (3 months) Rotation interval (days) | Early cold season (3 months) Paddock area (ha replicate$^{-1}$) | Early cold season (3 months) Rotation interval (days) | Stocking rate[B] (sheep months ha$^{-1}$) |
|---|---|---|---|---|---|---|---|
| | | | | *Experiment 1* | | | |
| RG24 | 3 | 8 | 1 | 10 | 1 | 15 | 24 |
| RG48 | 3 | 8 | 0.5 | 10 | 0.5 | 15 | 48 |
| CG24 | 3 | 8 | Growing + early cold season (6 months) – 2 ha per paddock of each replicate | | | | 24 |
| | | | | *Experiment 2* | | | |
| RG24 | 3 | 8 | | | 1 | 15 | 24 |
| RG48 | 3 | 8 | | | 0.5 | 15 | 48 |

[A]Treatments were: RG24 = 8 sheep grazed in a 1-ha growing season pasture with 24 SM ha$^{-1}$ for 3 months; RG48 = 8 sheep grazed in a 0.5-ha growing season pasture with 48 SM ha$^{-1}$ for 3 months; Growing + early cold season: CG24 = 8 sheep grazed in a single 2-ha plot with 24 SM ha$^{-1}$ for 6 months; RG24 = 8 sheep grazed in a 1-ha growing season pasture for 3 months and then transferred to a new 1-ha early cold season pasture for 3 months; RG48 = 8 sheep grazed in a 0.5-ha growing season pasture for 3 months and then transferred to a new 0.5-ha early cold season pasture for 3 months.

[B]Stocking rate = No. of sheep × grazing months paddock$^{-1}$.

bodyweight, and BWG is the rate of weight gain (kg day$^{-1}$) The $k_1$ values (MJ kg$^{-0.75}$) were 0.45 from July to October, 0.50 for November and 0.55 for December. The higher $k_1$ values for November and December reflect the decrease in ambient temperature, which gradually falls below zero in December. The $k_1$ values were from the work of Koong *et al*. (1985) and Degen and Young (2002). For these calculations $ME_g$ was taken as 30 MJ kg$^{-1}$ (Chen *et al*. 2010).

### Dry matter intake (DMI)

The DMI of experimental animals was calculated in two different ways and the results were compared. For each replicate of each treatment, the difference in herbage mass before and after grazing, corrected for herbage accumulation during grazing, was used to estimate the DMI by the equation of Smit *et al*. (2005) (Eqn 2):

$$\text{Group DMI } (\text{kg day}^{-1}\text{ paddock}^{-1}) = \frac{(a-b)\times(\log c - \log b)}{\log a - \log b} \quad (2)$$

where $a$ is the standing herbage DM (kg m$^{-2}$) just before grazing, $b$ is the standing herbage DM (kg m$^{-2}$) after grazing for 5 days, $c$ is the standing herbage DM (kg m$^{-2}$) on Day 5 in a cage ($1 \times 1$ m$^2$), placed onto the pasture just before grazing. Three cages in a paddock were measured to improve the accuracy of calculation.

One day before grazing, herbage samples were collected from three quadrats (0.25 m$^2$) randomly placed along a diagonal transect in each sub-paddock. On Day 5, three samples of herbage in the cage and three samples outside were collected. The group DMI was measured twice each month, and these values were used to calculate monthly group mean DMI using the equation of Smit *et al*. (2005) described above (Eqn 2).

Independently of the herbage removal calculation above, DMI for individual sheep was also estimated as the quotient of MEI (MJ head$^{-1}$ day$^{-1}$) and herbage ME (MJ kg$^{-1}$). For this purpose, the value assumed for herbage ME was taken as 10.5 MJ kg$^{-1}$ in June, reducing 0.5 MJ kg$^{-1}$ month$^{-1}$, reflecting herbage maturation and death through the growing season, and with the onset of freezing temperatures in the early cold season.

### Chemical analysis

The standing herbage was sampled at the same time as animal behaviour was observed each month. Samples were oven-dried at 65°C for 48 h and then weighed to measure DM. To determine the ash content, a portion of the dried sample was weighed, burned in a muffle furnace at 550°C for 4 h until all carbon had been removed, and then reweighed. Another portion of each sample was freeze-dried and finely ground for analysis of nitrogen (N), ether extract, and acid detergent fibre (ADF) and neutral detergent fibre (NDF) contents. The N concentration was determined as describe by Kjeldahl (1883) and the crude protein (CP) concentration was calculated by multiplying the N concentration by 6.25. The NDF and ADF concentrations were analysed sequentially using an ANKOM 2000 Fibre Analyser (ANKOM Technology, Fairport, NY, USA) following the protocol described by Van Soest (1963). The ether extract was analysed using an ANKOM XT15 Extractor (ANKOM Technology).

### Statistical analysis

One-way analysis of variance (ANOVA) was used to examine the effects of grazing treatments on bodyweight gain per head and per ha, feed intake, and grazing behaviour of Tibetan sheep, chemical composition of herbage, and standing herbage biomass. Differences among the means were considered to be significant at the $P = 0.05$ level. All statistical tests were performed using Statistical Package for the Social Sciences (SPSS) software, version 19.0 (SPSS Inc., Chicago, IL, USA).

## Results

### Standing herbage mass

Herbage mass data (Table 2) show that herbage accumulation was greater than herbage removal by grazing from in the growing season, but that herbage mass steadily declined with successive grazing rotations in the early cold season.

**Table 2. Standing herbage biomass (kg DM ha$^{-1}$) measured after grazing each month**

In each treatment of Experiments 1 and 2, growing season data collection occurred from 15 June to 15 September; early cold season data collection occurred from September 16 to December 15. s.d. = Standard deviation

| | Treatment[A] | | July | August | September | October | November | December |
|---|---|---|---|---|---|---|---|---|
| Experiment 1 | CG24 | Mean | 2360 | 3060 | 2710 | 2400 | 1810 | 1600 |
| | | s.d. | 159 | 134 | 95 | 133 | 72 | 142 |
| | RG24 | Mean | 1910 | 2030 | 2290 | 2410 | 1840 | 1630 |
| | | s.d. | 139 | 90 | 27 | 162 | 107 | 80 |
| | RG48 | Mean | 1900 | 2120 | 1940 | 2420 | 1710 | 1460 |
| | | s.d. | 51 | 106 | 120 | 93 | 178 | 124 |
| Experiment 2 | RG24 | Mean | – | – | – | 2415 | 1921 | 1544 |
| | | s.d. | – | – | – | 127 | 152 | 114 |
| | RG48 | Mean | – | – | – | 2307 | 1834 | 1440 |
| | | s.d. | – | – | – | 102 | 88 | 89 |

[A]Treatments were: RG24 = 8 sheep grazed in a 1-ha growing season pasture with 24 SM ha$^{-1}$ for 3 months; RG48 = 8 sheep grazed in a 0.5-ha growing season pasture with 48 SM ha$^{-1}$ for 3 months; Growing + early cold season: CG24 = 8 sheep grazed in a single 2-ha plot with 24 SM ha$^{-1}$ for 6 months; RG24 = 8 sheep grazed in a 1-ha growing season pasture for 3 months and then transferred to a new 1-ha early cold season pasture for 3 months; RG48 = 8 sheep grazed in a 0.5-ha growing season pasture for 3 months and then transferred to a new 0.5-ha early cold season pasture for 3 months.

### *Chemical composition of herbage in growing and early cold seasons*

In general, compared with early cold season herbage, growing season herbage was of better quality with a higher CP concentration and metabolic energy and lower concentration of ADF or NDF (Table 3). The CP concentration in the growing season was 35% higher than that in the early cold season and the concentrations of NDF and ADF in herbage during the growing season were ~8% and 5% lower, respectively, than those in the early cold season. The metabolic energy of herbage in the growing season was ~12% higher than it in the early cold season.

### *Effect of grazing system and stocking rate on BWG and DMI (CG vs RG)*

In Experiment 1, there was no significant difference between CG24 and RG24 in terms of BWG per head, BWG per ha, DMI or feed utilisation efficiency (Table 4), and animal behaviour, in either season (see Table 6). Meanwhile, the BWG per head and DMI were significantly lower in RG48 than in RG24 from the growing season, whereas BWG per ha and feed utilisation efficiency were higher in RG48 (Table 4, $P < 0.05$). When the data were combined across seasons, final BW was significantly higher in RG24 than in RG48, whereas BWG per ha was lower in RG24 than in RG48 (Table 4, all $P < 0.05$). There was no difference between RG24 and RG48 in BWG per head and DMI.

In Experiment 2, BWG per head was significantly higher in RG24 than that in RG48 (Table 5, $P < 0.01$), but there was no significant difference in terms of BWG per ha, feed utilisation efficiency and DMI between the two SR.

With respect to change throughout the season, the average DMI per sheep was approximately constant with time for each grazing regime in the growing season, but declined for all grazing systems as the early cold season progressed. (Fig. 1*a*); meanwhile the combination of constant intake (Fig. 1*a*) with increasing BW (Table 4) led to a steady decline in BWG during the growing season, exacerbated as the cold season progressed (Fig. 1*b*), with this pattern evident in all grazing systems.

**Table 3. Chemical composition (g kg$^{-1}$ dry matter, unless otherwise stated) of herbage samples during both experiment periods (growing season, 15 June–15 September; early cold season, 16 September–15 December)**

s.d. = Standard deviation; s.e.m. = Standard error of the means

| Chemical composition | Growing season | | Early cold season | | *P*-value | s.e.m. |
|---|---|---|---|---|---|---|
| | Mean | s.d. | Mean | s.d. | | |
| Dry matter (g kg$^{-1}$) | 326 | 48 | 809 | 63 | <0.001 | 22 |
| Ash | 64 | 2.9 | 61 | 1.8 | 0.008 | 1.1 |
| Crude protein | 95 | 9.1 | 59 | 6.8 | <0.001 | 3.8 |
| Neutral detergent fibre | 537 | 16 | 619 | 35 | <0.001 | 13 |
| Acid detergent fibre | 294 | 9.4 | 342 | 27 | <0.001 | 9.5 |
| Ether extract | 25.9 | 4.0 | 25.7 | 2.7 | 0.262 | 1.4 |
| metabolic energy (MJ kg$^{-1}$) | 10.3 | 0.29 | 9.2 | 0.24 | 0.008 | 0.24 |

**Table 4. Experiment 1: Effects of grazing management (continuous grazing and rotational grazing, CG and RG) and stocking rate[A] (sheep months ha$^{-1}$, SM ha$^{-1}$) on bodyweight gain and DMI[A] of Tibetan sheep during growing and early cold seasons**

s.e.m. = Standard error for the means

| Treatment | BW[B] at beginning (kg) | BW[B] at end (kg) | BWG[B] (g day$^{-1}$ head$^{-1}$) | BWG[B] (g day$^{-1}$ ha$^{-1}$) | DMI[A,C] (kg sheep$^{-1}$ day$^{-1}$) | Feed utilisation efficiency[B,C] (kg kg$^{-1}$) |
|---|---|---|---|---|---|---|
| | | | *Growing season*[D] | | | |
| RG24 | 33.1 | 47.6 | 150 | 1199 | 1.28/1.23 | 8.5/8.2 |
| RG48 | 33.1 | 45.0 | 122 | 1961 | 1.14/1.15 | 9.3/9.4 |
| s.e.m. | 0.08 | 0.68 | 11.9 | 61.0 | 0.064/0.065 | 0.91/0.85 |
| *P*-value | 0.892 | 0.018 | 0.032 | <0.001 | 0.071/0.280 | 0.035/0.020 |
| | | | *Growing + early cold season*[D] | | | |
| CG24 | 33.4 | 50.1 | 88.2 | 356 | 1.24/1.19 | 14.1/13.5 |
| RG24 | 33.1 | 49.0 | 68.5 | 338 | 1.18/1.14 | 17.2/16.6 |
| RG48 | 33.1 | 45.7 | 65.0 | 536 | 1.08/1.10 | 16.6/16.9 |
| s.e.m. | 0.23 | 0.59 | 25.7 | 16.2 | 0.080/0.054 | 6.03/4.78 |
| *P*-value | 0.267 | 0.001 | 0.623 | <0.001 | 0.060/0.124 | 0.391/0.406 |

[A]Stocking rate = No. of sheep × grazing months paddock$^{-1}$; DMI, dry matter intake.
[B]BW, bodyweight; BWG, bodyweight gain; Feed utilisation efficiency, DMI divided by daily BWG (kg kg$^{-1}$).
[C]The left hand value is calculated determined from the calculation of animal metabolic energy demand; the right hand value is derived from data on herbage disappearance, assessed by quadrat cutting.
[D]Growing season: RG24 = 8 sheep grazed in a 1-ha growing season pasture with 24 SM ha$^{-1}$ for 3 months; RG48 = 8 sheep grazed in a 0.5-ha growing season pasture with 48 SM ha$^{-1}$ for 3 months; Growing + early cold season: CG24 = 8 sheep grazed in a single 2-ha plot with 24 SM ha$^{-1}$ for 6 months; RG24 = 8 sheep grazed in a 1-ha growing season pasture for 3 months and then transferred to a new 1-ha early cold season pasture for 3 months; RG48 = 8 sheep grazed in a 0.5-ha growing season pasture for 3 months and then transferred to a new 0.5-ha early cold season pasture for 3 months.

**Table 5. Experiment 2: the effects of stocking rate[A] (sheep months $ha^{-1}$, SM $ha^{-1}$) on bodyweight gain and DMI[A] of Tibetan sheep during the early cold grazing season**

s.e.m. = Standard error for the means

| Treatment | BW[B] at beginning (kg) | BW[B] at end (kg) | BWG[B] ($g\ day^{-1}\ head^{-1}$) | BWG[B] ($g\ day^{-1}\ ha^{-1}$) | DMI[A,C] ($kg\ sheep^{-1}\ day^{-1}$) | Feed utilisation efficiency[B,C] ($kg\ kg^{-1}$) |
|---|---|---|---|---|---|---|
| RG24[D] | 46.6 | 48.0 | 15.4 | 123 | 1.11/1.06 | 72/69 |
| RG48[D] | 46.0 | 46.6 | 6.6 | 119 | 1.01/1.04 | 153/158 |
| s.e.m. | 0.73 | 0.74 | 2.45 | 33.0 | 0.125/0.078 | 18.4/20.07 |
| *P*-value | 0.432 | 0.108 | 0.010 | 0.896 | 0.468/0.797 | 0.240/0.386 |

[A]Stocking rate = No. of sheep × grazing months $paddock^{-1}$; DMI, dry matter intake.
[B]BW, bodyweight; BWG, bodyweight gain; Feed utilisation efficiency, DMI divided by daily BWG ($kg\ kg^{-1}$).
[C]The left hand value is calculated determined from the calculation of animal metabolic energy demand; the right hand value is derived from data on herbage disappearance, assessed by quadrat cutting.
[D]RG24 = 8 sheep grazed in a 1-ha early cold season pasture with 24 SM $ha^{-1}$ for 3 months; RG48 = 8 sheep grazed in a 0.5-ha early cold season pasture with 48 SM $ha^{-1}$ for 3 months. Early cold season pastures had not been grazed during growing season.

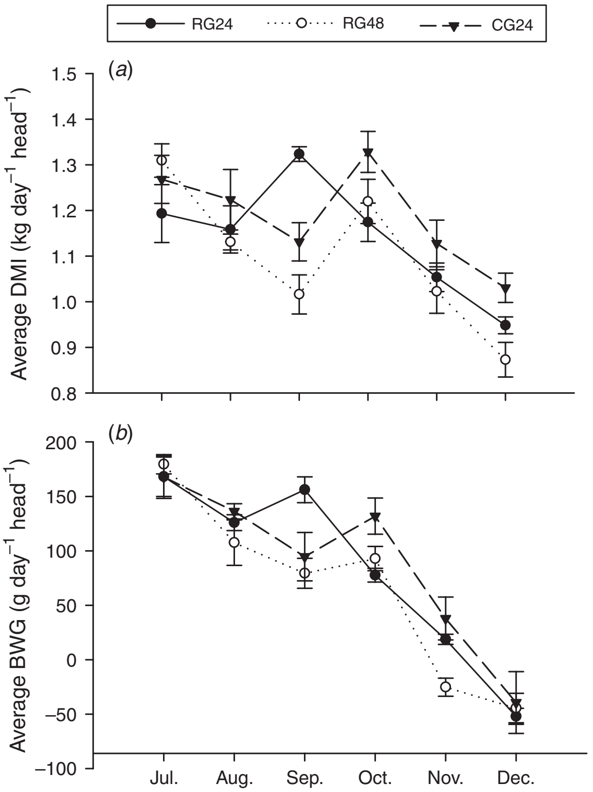


**Fig. 1.** Changes in average (*a*) dry matter intake (DMI) and (*b*) bodyweight gain per sheep under each treatment during the experimental period.

*Effect of grazing system and stocking rate on animal behaviour*

In the growing season, the high SR (RG48) significantly increased daily intake time, intake rate and the ratio of intake time : rumination time. However, compared with the sheep in RG24, those in RG48 had a shorter daily ruminating time and shorter intervals between boluses ($P < 0.05$) (Table 6). In the early cold season pasture intake time, intake rate, chewing time per bolus and the intake time : ruminating time ratio were significantly higher in RG48 than in RG24 (Table 7, $P < 0.05$). Compared with the sheep in RG48, those in RG24 had a longer daily ruminating time and faster walking rate (steps $min^{-1}$) while eating ($P < 0.05$).

*Relationship between ambient temperature and intake behaviour*

The data obtained from RG24 and CG24 were pooled and used to evaluate the effects of daylight ambient temperature on daily intake time and walking velocity while eating (steps $min^{-1}$), using linear regression (Fig. 2). Cold temperature significantly decreased intake time and walking velocity while eating (steps $min^{-1}$), but increased the number of bites per min ($P < 0.001$ in each case, $R^2 = 0.55$, 0.43 and 0.29, respectively).

## Discussion

*Effects of grazing management systems on animal performance and grazing behaviour*

For the past two decades, RG systems continue to be promoted and implemented (Norton 1998; Teague and Dowhower 2003). However, RG system were not always superior to CG in terms of the performance of animals grazed on rangelands, whatever it was cattle co-grazed with sheep (Kitessa and Nicol 2001), dairy cows (Pulido and Leaver 2003) or sheep (Hao *et al*. 2013). This conclusion was also supported by the results of later studies (Derner and Hart 2007; Hunt *et al*. 2014; Sun *et al*. 2015). In the present study, we did not find any significant difference in BWG per head or BWG per ha between CG and RG systems at a SR of 24 SM $ha^{-1}$. Although there was no effect of the grazing system, BW at the end of grazing and BWG per head tended to be higher under CG than under RG in both the growing season and the early cold season (50.1 vs 49.0 kg BW; 88.2 vs 68.5 g $day^{-1}$ $head^{-1}$). Woodward *et al*. (1995) reported that compared with RG, CG allowed animals to maximise feed intake because herbage and grazing time did not limit feed intake. Our results also indicated that there was a marginally higher DMI under CG than under RG (Table 4), although the difference was not statistically significantly. Therefore, it can be expected that animals in the CG system have a greater opportunity to select palatable herbage. In comparison, the RG system where animals were rotated within small sub-paddocks resulted in a higher

**Table 6. Experiment 1: Effects of grazing management (continuous grazing and rotation grazing, CG and RG) and stocking rate (sheep months ha$^{-1}$, SM ha$^{-1}$) on feed intake and ruminating activities of Tibetan sheep during growing and early cold seasons**

s.e.m. = Standard error for the means

| | Growing season [A] | | s.e.m. | *P*-value | Growing + early cold season[A] | | | s.e.m. | *P*-value |
|---|---|---|---|---|---|---|---|---|---|
| | RG24 | RG48 | | | CG24 | RG24 | RG48 | | |
| Daily intake time (min daylight$^{-1}$) | 440 | 475 | 10.2 | 0.027 | 393 | 410 | 436 | 25.1 | 0.250 |
| Intake rate (bites min$^{-1}$) | 34.7 | 37.8 | 0.69 | 0.011 | 38.9 | 36.4 | 38.0 | 1.34 | 0.212 |
| Bite weight (g)[B] | 0.080 | 0.062 | 0.007 | 0.065 | 0.078 | 0.078 | 0.065 | 0.004 | 0.013 |
| Walking velocity while eating (steps min$^{-1}$) | 5.34 | 5.09 | 0.156 | 0.195 | 5.83 | 5.01 | 4.78 | 0.422 | 0.060 |
| Number of steps/daylight (×1000) | 2.35 | 2.42 | 0.116 | 0.584 | 2.31 | 2.06 | 2.11 | 0.268 | 0.636 |
| Daily ruminating time (min daylight$^{-1}$) | 250 | 215 | 10.3 | 0.027 | 188 | 169 | 140 | 43.4 | 0.548 |
| Number of chews per bolus | 57.2 | 59.8 | 1.27 | 0.106 | 68.0 | 61.7 | 63.2 | 3.79 | 0.251 |
| Chewing time per bolus (s) | 39.7 | 42.0 | 1.27 | 0.151 | 44.6 | 43.0 | 43.7 | 2.74 | 0.840 |
| Interval between boluses (s) | 5.09 | 4.80 | 0.086 | 0.027 | 5.50 | 5.34 | 5.17 | 0.321 | 0.590 |
| Intake time : ruminating time | 1.77 | 2.22 | 0.114 | 0.018 | 2.63 | 2.98 | 3.46 | 0.820 | 0.608 |

[A]Growing season: RG24 = 8 sheep grazed in a 1-ha growing season pasture with 24 SM ha$^{-1}$ for 3 months; RG48 = 8 sheep grazed in a 0.5-ha growing season pasture with 48 SM ha$^{-1}$ for 3 months; Growing + early cold season: CG24 = 8 sheep grazed in a single 2-ha pasture with 24 SM ha$^{-1}$ for 6 months; RG24 = 8 sheep grazed in a 1-ha growing season pasture for 3 months and then transferred to a new 1-ha early cold season pasture for 3 months; RG48 = 8 sheep grazed in a 0.5-ha growing season pasture for 3 months and then transferred to a new 0.5-ha early cold season pasture for 3 months. Early cold season pastures had not been grazed during growing season.

[B]Bite weight: Dry matter intake (g day$^{-1}$)/(Daily intake time (min day$^{-1}$) × Intake rate (bites min$^{-1}$)).

**Table 7. Experiment 2: Effects of stocking rate (sheep months ha$^{-1}$, SM ha$^{-1}$) on feed intake and ruminating activities of Tibetan sheep during winter**

s.e.m. = Standard error for the means

| Variable | Treatment | | s.e.m. | *P*-value |
|---|---|---|---|---|
| | RG24[A] | RG48[A] | | |
| Daily intake time (min daylight$^{-1}$) | 372 | 398 | 2.7 | <0.001 |
| Intake rate (bites min$^{-1}$) | 37.7 | 39.3 | 0.41 | 0.018 |
| Bite weight (g)[B] | 0.077 | 0.068 | 0.006 | 0.214 |
| Walking velocity while eating (steps min$^{-1}$) | 4.7 | 4.5 | 0.07 | 0.042 |
| Number of steps/daylight (×1000) | 1.75 | 1.80 | 0.021 | 0.074 |
| Daily ruminating time (min daylight$^{-1}$) | 109 | 79 | 2.8 | <0.001 |
| Number of chews per bolus | 67.9 | 69.6 | 0.49 | 0.025 |
| Chewing time per bolus (s) | 46.2 | 46.9 | 0.44 | 0.174 |
| Interval between boluses (s) | 5.23 | 5.16 | 0.118 | 0.595 |
| Intake time : ruminating time | 3.42 | 5.07 | 0.210 | <0.001 |

[A]RG24 = 8 sheep in a 1-ha early cold season pasture with 24 SM ha$^{-1}$ for 3 months; RG48 = 8 sheep in a 0.5-ha early cold season pasture with 48 SM ha$^{-1}$ for 3 months. Early cold season pastures had not been grazed during growing season.

[B]Bite weight: Dry matter intake (g day$^{-1}$)/(Daily intake time (min day$^{-1}$) × Intake rate (bites min$^{-1}$)).

grazing intensity, so animals would be expected to have a less selective grazing behaviour and ingest less desirable plants (Stuth *et al*. 1987). Diet selection can affect the nutrient supply and digestibility in grazing animals (Arnold 1960*a*; Wang *et al*. 2009). In our study, the difference in average BWG and DMI between the two grazing systems gradually decreased through the progression of seasons from late the growing season into the early cold season (Fig. 1), and the BWG per sheep in all treatments became negative from late November. This result indicates the point in the seasonal transition from the growing season to the early cold season at which the bodyweight loss described by Ren *et al*. (2008), and attributable to declining herbage quality (Table 3) begins to occur. Retention of stock beyond this point in a seasonal grazing system would likely be uneconomic, unless rewarded by an increase in product price.

Grazing behavioural activities, such as daily intake time, intake rate and walking distances differ considerably between field-grazed and confined animals (Animut *et al*. 2005), as a result of the interactions between the animal and the environment (Baumont *et al*. 2004). Activities related to ingestion are the most important part of grazing. In this study, neither intake activities nor ruminating activities differed significantly between the CG and RG systems. However, daily intake time and the number of steps taken per minute while eating decreased and the intake rate increased as the temperature decreased (Fig. 2). The CP content in forage and standing herbage decreased from the growing season

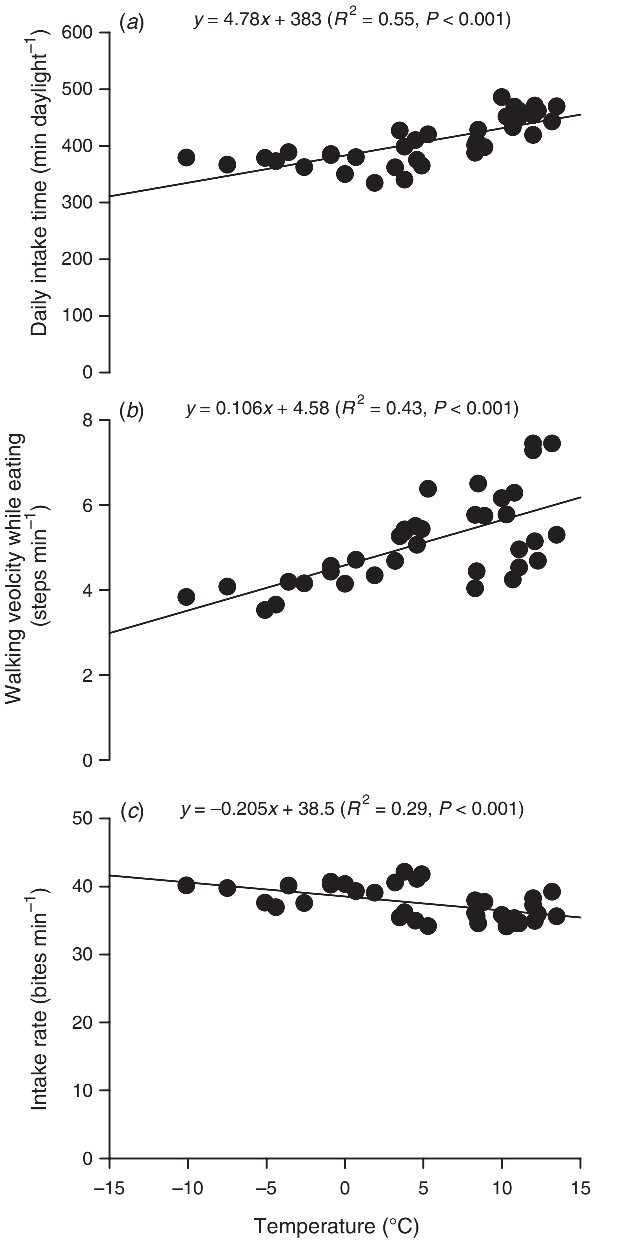


**Fig. 2.** Relationships between average daylight ambient temperature and (*a*) daily intake time in daylight, (*b*) walking velocity while eating in daylight and (*c*) intake rate using data obtained from continuous and rotational grazing systems at the same stocking rate (24 sheep months $ha^{-1}$) in both the growing and the early cold season.

to the early cold season in both the CG and RG systems (Tables 2 and 3), but the intake rate increased (Fig. 3). These results suggested that the sheep tended to reduce their energy costs while trying to meet their energy needs in the early cold season when the accessible forage was restricted.

Osuji (1974) stated that the time spent grazing was directly associated with the energy cost for grazing ($r = 0.86$), whereas in other contexts, intake restriction can result in a compensatory increase in grazing time (Arnold 1960*b*, 1962; Animut *et al.* 2005; Lin *et al.* 2011). Estimation of mean bite size from dividing daily intake (Table 4) by bites $day^{-1}$ (Table 6) indicates values of 0.06–0.08 g $bite^{-1}$ and these values for bite size in sheep grazing temperate pastures would be associated with a bite rate of 60–70 bites $min^{-1}$ and herbage height of ~70 mm (fig. 3 of Allden and McDWhittaker 1970). This would seem to confirm the finding of Chen *et al.* (2010) that local sheep grazing native grassland in China are adapted to taking smaller bites than their temperate counterparts.

We found that the SR had a considerable effect on the grazing behaviour of Tibetan sheep. For example, in both the growing and early cold season, sheep at the higher SR treatment spent more time in grazing and less time ruminating than did those at the lower SR. Similar results were reported by Animut *et al.* (2005) and Askar *et al.* (2013). Grazing pressure under RG is usually linked to a high animal density (especially at higher SR) on each grazed block, albeit for a shorter period. Consequently, sheep spend less time selecting desirable plants, which may influence their nutrient supply (Stuth *et al.* 1987). Thus, it was expected the sheep at the lower SR in this study would have a significantly higher BWG per head than those at the higher SR, even when the standing herbage mass was around 200 g $m^{-2}$ (2000 kg $ha^{-1}$).

Rumination is a necessary physical process for the degradation and digestion of consumed food in the rumen and other parts of the digestive tract of ruminant animals. However, few studies have evaluated the effects of the SR on the rumination behaviour of Tibetan sheep. In this study, we observed that the rumination time was shorter in sheep at the higher SR than in those at the lower SR. This finding is consistent with the lower DMI at higher SR likely also indicates less readily available nutrient supply to the rumen, leading to the lower BWG per head.

### *Effects of stocking rate on animal performance and grazing behaviour*

In the RG system, SR is the key factor affecting both plant and animal responses to grazing (Briske *et al.* 2008). Increase in SR can decrease standing herbage mass on the pasture (Ganjurjav *et al.* 2015) and reduce the quantity of feed intake per bite (Lin *et al.* 2011). Reduced bite size at higher SR was noted in this study (Table 6) and the increased grazing time is likely a spontaneous compensation by the animals, without which DMI of animals would have been even more reduced at higher SR than the values observed (Table 4).

The BWG is an important indicator for to prediction of optimal SR in rangeland management (Wang *et al.* 2009). Increasing the SR has been shown to linearly decrease individual animal performance (Zhou *et al.* 1995*a*, 1995*b*; Owensby and Auen 2013), whereas animal performance per ha responds to the SR in a parabolic manner (Zhou *et al.* 1995*a*; Sun *et al.* 2015). However, in the present study, higher BWG per ha was achieved at higher SR (Table 4), which can only come from increased herbage harvested as a result of increased animal numbers, even though this is not strongly evident in Table 2. However, this pattern of response involving increased per ha performance associated with decreased per animal production as SR increases is typical of agricultural systems as the SR approaches the ecological carrying capacity of the system. From this point further increase in SR is

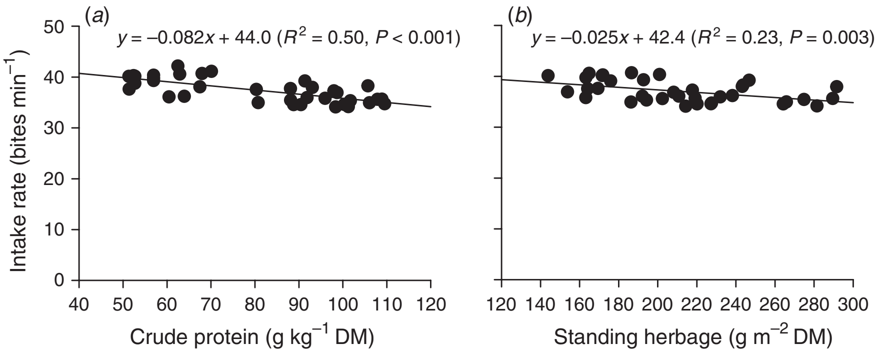


**Fig. 3.** Relationships between intake rate and (*a*) crude protein and (*b*) standing herbage using data obtained from continuous and rotational grazing systems at the same stocking rate (24 sheep months ha$^{-1}$) in both the growing and the early cold season.

likely to decrease both per animal and per ha production, both in temperate pastoral systems and on the QTP (Miao *et al*. 2015).

The BWG per head was much lower in the early cold season than in the growing season (15.4 and 6.6 g vs 150 and 122 g in the 24 and 48 SM ha$^{-1}$ treatments, respectively). Sun *et al*. (2015) reported a considerable BW loss of Tibetan sheep in the early cold season regardless of the SR on the QTP. The poor pasture quality and limited amount of available biomass are the main factors contributing to poor performance in the cold season, and poor weather conditions are other factors (Zhou *et al*. 1995*a*). The QTP is very cold in the cold season with ambient temperatures below 0°C and continuous snow cover. These harsh weather conditions coupled with the short daylength in the cold season can reduce the daily grazing time. As shown in Fig. 1, as the daily ambient temperature increased, the daily grazing time and walking distance during grazing increased. Therefore, where possible, stock seasonally grazed in the growing season should be sold before the point where weight loss sets in, for best overall feed conversion efficiency.

### *Sustainable stocking rate and recommendations for industry extension workers*

The data, especially the finding of similar animal performance for CG and RG systems, suggest that a SR of 24 SM ha$^{-1}$ in the growing season is within the ecological sustainable carrying capacity of this rangeland. However, the reduced performance per animal at a SR of 48 SM ha$^{-1}$ suggests this stocking rate is near the short-term sustainable carrying capacity of the rangeland. Calculation of animal intake independently from metabolic energy equations and herbage disappearance as assessed from cut quadrats gave reassuringly consistent values (Table 4). Based on the estimated DMI (Table 4) for 8 or 16 sheep per ha grazing for 3 months in the 24 SM ha$^{-1}$ and 48 SM ha$^{-1}$ stocking rates, the sustainable forage production capacity of this rangeland is in the range 900–1500 kg DM ha$^{-1}$ year$^{-1}$, and maintenance of animal bodyweight becomes impossible after mid-November (Fig. 1*b*) as a result of falling temperatures and declining herbage quality. It is therefore recommended that in the planning of future farming systems in this region, annual herbage requirements of animals do not exceed these levels, and winter grazing is avoided if possible, or feed supplementation used.

## Conclusion

The results of this study provide new information on the grazing management of sheep on the rangelands of the QTP in north-western China. The grazing system (CG vs RG) did not significantly affect the growing performance or feed utilisation efficiency when sheep were managed under a low SR (24 sheep months ha$^{-1}$, SM ha$^{-1}$). The annual herbage demand of animals that is ecologically sustainable for pasture systems in this region would appear to be ~1500 kg DM ha$^{-1}$, and animals on a pasture only diet are not able to maintain their bodyweight in the cold season after mid-November. The proposed production system trialled in this experiment of seasonal grazing of growing animals in the growing season on the QTP would be inherently more efficient (48 SM ha$^{-1}$ in growing season pasture and 24 SM ha$^{-1}$ in early cold season pasture) than present overwintering systems, because animals could be sold before weight loss occurs in the cold season, or retained tactically with supplementary feed to catch market premiums where relevant.

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