African Journal of Biotechnology Vol.11 (41), pp. 9894-9905, 22 May, 2012
Available online at http://www.academicjournals.org/AJB
DOI:10.5897/AJB12.843
ISSN 1684-5315 © 2012 Academic Journals

Full Length Research Paper

Optimum stocking rate for goat production on improved highland pastures in South-western China

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Accepted 27 April, 2012

The effects of four stocking rates (SR; 7.5, 15, 30 and 45 goats ha^{-1}) on goat performance and herbage productivity were examined on the perennial pastures. The experiment was applied by grazing 65 six-months old Chinese Yunling black goat wethers for two years. Significant year × SR interactions were observed on standing crop (SC). A linear negative correlation was found for average daily gain (ADG) and SR, and a linear positive correlation for ADG and SC was found. SR had a significant quadratic relationship to gain per hectare (GH), but a significant linear negative relationship to SC. The SR at which GH was optimal ranged from 29.1 to 34.3 goats ha^{-1}, with corresponding levels of SC in the range of 138.9 to 150.1 g DM m^{-2} and utilization rate of pasture ranged from 63.1 to 74.3%. The study therefore provided a sustainable utilization approach for sown pastures in south-west China.

Key words: Black goat, grazing intensity, average daily gain, gain per hectare, South-west China.

INTRODUCTION

Grazing mixed perennial grass and white clover sown pastures are used in many countries because of the higher grass productivity and stocking rates compared with natural grasslands (Penning et al., 1996). In an attempt to obtain maximum utilization of forages, many improved pastures in southwest China have been intensively overgrazed and followed by serious degradation. An important production consideration is stocking rate (SR), which has an over-riding impact on livestock performance and pasture sustainability (Sollenberger et al., 2005). Setting an optimum stocking rate (SR) for perennial pastures is a major approach for prevention of degradation. Previous analyses of SR have concentrated mostly on relating average daily gain (ADG) and gain per hectare (GH) to SR (Quigley et al., 1984; Bransby, 1985). The objectives of these studies were to carry as many animals as possible for maximum profit. The relationships between ADG and standing crop (SC) and between SR and SC have not been carefully considered (Bransby et al., 1988). Therefore, separate regressions were used to relate ADG to SC, SR to ADG, SR to SC, and SR to GH in this study.

About 152 million goats in 2009 are found in China, accounting for 17.3% of the world goat population (FAOSTAT, 2009). The effect of SR on mixed perennial pastures for cattle and sheep has been well documented in China (Jiang and Li, 1993; Wa et al., 1994), but nothing has been reported for goats. Goats prefer and spend more time than sheep on consuming graze plants (Ngwa et al., 2000). Therefore, goats were used in this experiment to determine the effect of SR on herbage productivity and animal growth during the grazing season and to identify the optimum SR for typical perennial pastures in south-west China. The achievements of this study will be instructive for the pasture-goat system

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management in developing countries.

MATERIALS AND METHODS

All animal-use procedures were reviewed and approved by the China Agricultural University Laboratory Animal Care Advisory Committee.

Study location

The study site is located on improved highland pastures in Tianba village (20°45′N, 103°48′E; 2,420–2,525 m a.s.l), approximately 132 km south of Huize county, Yunnan Province, China. The primary soil type on this site is red loam with pH 5.8 (Huize Pasturage Bureau and Forage Monitoring Station). Mean annual (1985 - 2007) precipitation was 988.4 mm, with approximately 60% of rain falling through June to August. Average annual temperature was 14.3°C, with -5.5°C being the lowest temperature in January and 28.3°C the highest temperature in June. Approximately 220 days are frost free. Climatic information on mean monthly precipitation and air temperature in 2008 and 2009 are shown in Figure 1.

Pasture survey and management

Pasture of white clover (*Trifolium repens* cv. Huia), perennial ryegrass (*Lolium perenne* cv. Eminent) and cocksfoot (*Dactylis glomerata* cv. Amba) was established in May 2002. As at when the grazing experiment began in 2008, the pasture vegetation with 96 to 98% coverage consisted of *T. repens* (15.3%), *L. perenne* (13%), *D. glomerata* (33.2%), *Eragrostis ferruginea* (8.6%), *Imperata cylindrica* (6.9%) and various weeds (20.6%).

Experimental design

There were two consecutive years (2008 and 2009) of grazing with each trial lasting 28 weeks from March until October. In total, 65 six-month-old healthy Chinese Yunling black goat wethers were used for the experiment. All goats were weighed, ear-tagged, introduced into the experimental area in mid-March of each year, and allowed seven days pretreatment to adjust to grazing. Initial body weights (BW) were confirmed in late-March of each year, and goats were randomly partitioned into four groups according to SR and initial BW. The identification of SR, initial BW, grazing areas and actual goat numbers for grazing intensity treatments during 2008 and 2009 are presented in Table 1. Goats were weighed individually at monthly intervals after a 15-h fast without feed and water. BWs were determined as the average of weights from two consecutive days' measurements to reduce experimental error. Goats continued to graze for 8 h and had free access to water and mineralized salt, and then were kept overnight in pens with a double-deck floor. Initial, final and 30-day incremental weights were used to calculate ADG and GH. Sick or dead goats during the experimental period were treated or replaced with healthy goats of similar BW and age. No hay was provided during the experiment.

Four fields were fenced to enclose areas of 0.67 ha and stocked continuously at four different SR of 7.5, 15, 30 and 45 goats ha^{-1} (Table 1). SR for light grazing (LG), medium grazing (MG), high grazing (HG) and very high grazing (VHG) were achieved by varying animal numbers, so that 5, 10, 20 and 30 goats were grazed in each field. SR in this experiment was calculated using the following equation:

$$SR = Y \times R \times I^{-1} \times d^{-1}$$

Where, Y = local pasture dry matter yield (kg DM ha^{-1}); R = pasture utilization ratio (35, 50, 65 or 80%) for four SR (7.5, 15, 30 and 45 goats ha^{-1}), according to the investigation by the Huize Pasturage Bureau and Forage Monitoring Station; I = theoretic daily intake (kg DM d^{-1}goat^{-1}), and d = number of grazing days in the local region.

Herbage sample collection and measurement

Herbage samples were measured using moveable cages (McNaughton et al., 1996; Holland et al., 2008). Three portable wire mesh cages, 1.5 m long × 1.5 m wide × 1.0 m high, with a mesh size of 15 × 10 cm were installed within each paddock with metal pegs. The cages prevented any grazing by goats on the caged area. After sampling, cages were moved to new locations. Successive paddock-herbage samples were taken at the beginning of the grazing experiment and continued every 28 days by hand clipping to ground level. Total herbage mass and SC were estimated on three paired 0.5-m^2 square frames, and litter was cleared out inside or outside of cages before cut herbage. All herbage samples were dried to a constant weight in a forced-air oven at 65°C for 48 h, and then mean monthly SC values were calculated for each area.

Statistical analysis

Data were analyzed using SPSS 13.0 (SPSS Inc., Chicago, IL, USA), and significance was declared at $P<0.05$. Analysis of variance was used to test the effects of SR on monthly SC, ADG and GH for each period. The GLM procedure of SPSS was used to analyze duplicated data obtained over the 2-year study. The model included SR, year, and the interaction of SR × year, with SR as a fixed effect and year as a random effect. ADG were calculated as the difference between the initial and monthly interval weights divided by the number of days between weights. The GH was determined from the product of SR × ADG × days. The number of days was the monthly interval for the goat weighing. Regression analysis was then used to describe the complex relationship between animal growth, SC and SR.

Previous regression models have concentrated mostly on relating ADG and GH to SR (Jones and Sandland, 1974; Bransby, 1984). In Jones and Sandland (1974), the relationship between gain per animal (Ya) and SR is a simple linear model of the form:

$$Ya = a - b \times SR \tag{1}$$

Where, a and b are constants, and the relationship between GH and SR is a quadratic of the form:

$$GH = a \times SR - b \times SR^2 \tag{2}$$

The optimum SR for maximum GH could be calculated from the linear regression Equation (1) by $a/2b$. Maximum GH is derived from Equation 2. However, little information on pasture has been mentioned in literature. Consequently, Bransby et al. (1988) suggested that the responses of ADG and GH to SC over the season would have more relevance for continuous grazing, and the maximum GH would be determined by the level of SC. The relationships between ADG and SC, and SC and SR are set up as follows:

$$ADG = b_0' + b_1' \times SC \tag{3}$$

$$SC = b_0'' + b_1'' \times SR \tag{4}$$

Where, b_0', b_1', b_0'' and b_1'' are constants. The optimum SR is also derived from Equations 1 and 2. The level of SC that resulted in

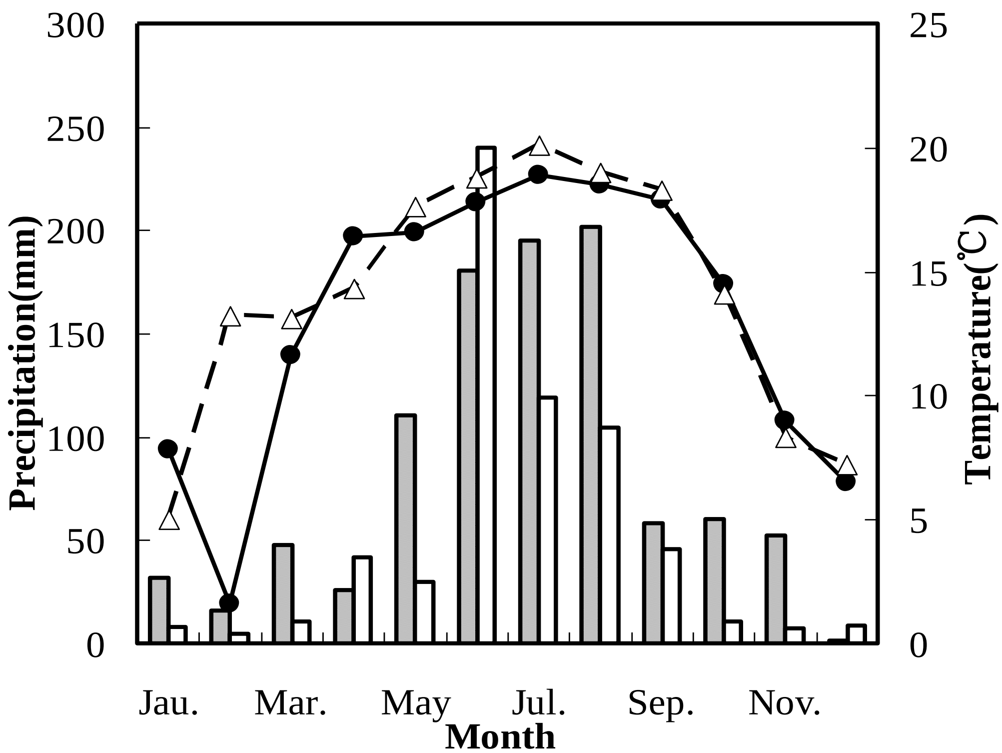


Figure 1. Mean monthly temperature (°C, lines) and precipitation (mm, bars) measured at Huize County, Yunnan Province, China in 2008 and 2009. Lines with black circles and white triangles represent 2008 and 2009 temperatures, respectively; shadow and white bars represent 2008 and 2009 precipitation, respectively.

Table 1. Summary data including stocking rate (SR, goats ha^{-1}), initial body weight (BW, Kg) and actual goat numbers for grazing trials.

Grazing intensity	SR goats ha^{-1}	Initial BW (kg)		Actual goat numbers head
		2008	2009	
Light grazing (LG)	7.5	20.0 (0.2)	18.1 (0.6)	5
Medium grazing (MG)	15	19.3 (0.1)	17.4 (0.3)	10
High grazing (HG)	30	19.8 (0.2)	17.8 (0.3)	20
Very high grazing (VHG)	45	19.4 (0.2)	17.6 (0.3)	30

Values in parentheses are standard errors.

maximum GH was estimated by taking the optimum SR value back into Equation 4. Hence, in this experiment, the following method to calculate SR, SC and GH is based on the relationships between SR and GH, SR and SC. Because of different units between GH and SC values, it is hard to find intersections between them.

For convenience, to calculate the optimum SR range, GH and SC values are changed to the ratio GH′ and SC′ by unifying the units:

$$GH' = GH/GH_{max} \quad (5)$$

$$SC' = SC/SC_{max} \quad (6)$$

Where, GH_{max} and SC_{max} are the maximum gain per hectare (74.7 kg ha^{-1}) and maximum SC (284.11 g DM m^{-2}) values from the 2-year grazing period data. The relationships between GH′ and SR, and SC′ and SR can be derived from the following equations:

$$GH' = a_1 \times SR - b_1 \times SR^2 \quad (7)$$

$$SC' = a_2 - b_2 \times SR \quad (8)$$

Where, a_1, b_1, a_2 and b_2 are constants. The SR at which maximum GH occurred was estimated by $a_1/2b_1$, maximum GH value is derived from Equation 7 and 5, and maximum SC value is derived from Equation 8 and 6. The range of SR, where GH and SC intersect together, can be estimated by equating the Equation 7 to 8, and then the stocking rates are calculated by finding solutions to Equation 9:

$$GH' = SC' \quad (9)$$

Table 2. SR, year, and year × SR interaction effects on mean values of standing crop (SC, g DM m^{-2}) during the grazing period.

Item		SC (g DM m^{-2})				Level of significance		
		LG	MG	HG	VHG	Year	SR	Year × SR
Df						1	3	3
2008	April	120.3 (5.4)	113.0 (5.7)	104.1 (11.8)	86.7 (4.9)		*NS*	
	May	132.2 (5.1)^{bc}	159.1 (11.2)^{c}	105.7 (10.4)^{ab}	95.6 (4.6)^{a}		* *	
	June	147.3 (13.2)	147.6 (9.5)	127.3 (9.0)	115.9 (1.3)		*NS*	
	July	177.6 (11.4)^{b}	192.2 (10.1)^{b}	132.4 (11.5)^{a}	127.4 (7.0)^{a}		* *	
	August	284.1 (10.8)^{c}	244.9 (10.2)^{c}	198.2 (16.9)^{b}	146.1 (12.3)^{a}		* * *	
	September	256.6 (17.5)^{c}	226.9 (10.2)^{c}	170.1 (7.8)^{b}	128.1 (11.4)^{a}		* * *	
	October	202.2 (6.7)^{c}	183.1 (13.8)^{bc}	152.2 (7.1)^{b}	111.1 (14.0)^{a}		* *	
	Mean	188.6 (3.9)^{c}	181.0 (3.9)^{c}	141.4 (3.9)^{b}	116.0 (3.9)^{a}	* * *	* * *	* * *
2009	April	134.7 (13.0)	107.0 (7.9)	102.7 (6.6)	101.2 (8.5)		*NS*	
	May	137.3 (16.9)	126.2 (8.6)	102.1 (8.0)	90.0 (9.6)		*NS*	
	June	161.7 (12.9)^{c}	132.4 (4.4)^{bc}	106.2 (9.4)^{ab}	95.1 (10.4)^{a}		* *	
	July	216.8 (8.8)^{c}	187.2 (5.2)^{c}	147.8 (15.3)^{b}	110.4 (12.9)^{a}		* * *	
	August	244.2 (12.4)^{b}	217.8 (12.2)^{b}	154.3 (4.5)^{a}	126.0 (13.7)^{a}		* * *	
	September	209.8 (12.2)^{c}	175.6 (12.1)^{bc}	139.4 (10.6)^{b}	99.4 (13.9)^{a}		* * *	
	October	190.2 (13.7)^{c}	153.4 (14.2)^{c}	111.8 (14.8)^{b}	70.3 (5.1)^{a}		* * *	
	Mean	185.0 (4.2)^{d}	157.1 (4.2)^{c}	123.5 (4.2)^{b}	98.9 (4.2)^{a}	* * *	* * *	* *

Values in parentheses are standard errors. Within a row, means without a common superscript differ (P<0.05). *P<0.05; **P<0.01; ***P<0.001; *NS,* not significant (P>0.05).

$$SR = [(b_2 + a_1) \pm \sqrt{(b_2 + a_1)^2 - 4 \times b_1 \times a_2}\,] / (2 \times b_1) \tag{10}$$

Taking the SRs (100) back into Equations 7 and 8, we can calculate the ratio GH′ and SC′. Similarly, the level of GH and SC can be estimated by finding the solutions to Equations 5 and 6.

RESULTS

Standing crop

There were significant SR (P<0.01) and year (P<0.001) effects, and a SR × year interaction (P<0.001) on mean SC (Table 2). Mean SC were less for treatments MG, HG and VHG in 2009 versus 2008, but values were similar between years for treatment LG. In 2008, mean SC significantly decreased in treatments HG and VHG (P<0.001), and were not significantly different between treatments LG and MG (P>0.05). However, highly significant differences (P<0.001) were detected among all the treatments in 2009; the order is LG > MG > HG > VHG. Compared with treatments LG, MG and HG, the mean SC values in treatment VHG reduced by 38.5, 35.9 and 18.8% in 2008 and 46.5, 37.0 and 19.9% in 2009, respectively.

SR also had marked effects on monthly changes of SC (P<0.01), except in the initial months in each year. Monthly SC values were similar at the two lower SR over the year in which they were measured, and the values were lowest in treatment VHG (45 goats ha^{-1}) compared with areas grazed at 7.5, 15 and 30 goats ha^{-1} (P<0.01) for two years. In 2008, significant differences between treatments HG and VHG were observed from August, but the differences were observed one month later in 2009. Monthly SC values in all treatments increased as the grazing season progressed, with the greatest SC values occurring in August, and then decreasing after the peak. Furthermore, increasing the SR from 7.5 to 45 goats ha^{-1} decreased the SC by 48.6 and 48.4% in August of 2008 and 2009, respectively. Compared with treatments HG and VHG, SC in treatments LG and MG increased rapidly from June to August, but the increments were greater in 2008 versus 2009. It is apparent that SC values were quite low on treatment VHG after grazing in September (99.4 g DM m^{-2}) and October (70.3 g DM m^{-2}) of 2009 below 1000 kg ha^{-1} levels.

Average daily gain and gain per hectare

Grazing year and SR are also important factors affecting animal performance. Both year (P<0.001) and SR (P<0.001) had significant effects on goat ADG and GH (Table 3). However, there was not a trend of SR × year interaction (P>0.05) in overall ADG. The seasonal changes of ADG and GH for all grazing treatments in 2008 and 2009 are shown in Figures 2 and 3. Similar with

Table 3. Mean values for the fixed effect of SR, year, and year × SR interaction on goat performance at each time period.

Item		SR (goats ha^{-1})				Level of significance		
		7.5	15	30	45	Year	SR	year × SR
Df						1	3	3
ADG (g goat^{-1}day^{-1})								
2008	Initial value‡	21.0 (10.8)	17.4 (10.0)	6.5 (8.3)	-8.7 (6.4)		*NS*	
	Peak value ‡	103.2 (6.3)^{b}	97.7 (6.1)^{b}	73.2 (5.5)^{a}	51.6 (5.4)^{a}		* * *	
	Final value ‡	36.7 (8.9)^{ab}	42.7 (8.7)^{b}	40.0 (9.1)^{ab}	3.3 (8.3)^{a}		* *	
	Mean	53.5 (5.3)^{b}	54.1 (3.7)^{b}	45.3 (2.6)^{b}	18.4 (2.2)^{a}	* * *	* * *	*NS*
2009	Initial value	44.0 (7.5)^{b}	45.6 (11.2)^{b}	41.2 (7.3)^{b}	10.7 (6.8)^{a}		* *	
	Peak value	110.0 (8.2)^{b}	100.0 (3.7)^{b}	73.1 (7.1)^{a}	55.3 (5.4)^{a}		* * *	
	Final value	17.0 (7.9)^{b}	56.8 (13.1)^{c}	38.0 (8.6)^{bc}	-24.1 (7.9)^{a}		* * *	
	Mean	55.9 (6.2)^{b}	61.9 (4.4)^{b}	50.3 (3.1)^{b}	17.8 (2.5)^{a}	* * *	* * *	*NS*
GH (kg ha^{-1})								
2008	Initial value	4.9 (2.5)	8.1 (4.7)	6.0 (7.7)	-12.2 (8.9)		*NS*	
	Peak value	24.0 (1.5)^{a}	45.5 (2.8)^{ab}	68.1 (5.1)^{b}	72.0 (7.5)^{b}		* *	
	Final value	8.3 (2.0)	19.2 (3.9)	36.0 (8.2)	4.5 (11.2)		*NS*	
	Mean	12.3 (6.1)^{a}	24.8 (4.3)^{b}	41.5 (3.0)^{c}	25.4 (2.5)^{b}	* * *	* * *	*NS*
2009	Initial value	8.3 (1.4)	17.1 (4.2)	30.9 (5.5)	12.0 (7.7)		*NS*	
	Peak value	24.8 (1.8)^{a}	45.0 (1.7)^{ab}	65.8 (6.4)^{bc}	74.7 (7.3)^{c}		* *	
	Final value	3.8 (1.8)^{ab}	25.5 (5.9)^{b}	34.2 (7.8)^{b}	-32.5 (10.6)^{a}		* * *	
	Mean	12.3 (6.9)^{a}	27.1 (4.9)^{b}	44.0 (3.5)^{c}	23.5 (2.8)^{ab}	* * *	* * *	*

Values in parentheses are standard errors. Within a row, means without a common superscript differ (P<0.05). *P<0.05; **P<0.01; ***P<0.001; *NS* not significant (P>0.05). ‡Beginning value, peak value and end value represent values in April, August and October, respectively.

the monthly changes of SC, ADG and GH gradually increased from April to August and dramatically decreased from September to October. In both years, maximum ADG and GH values all occurred in August, while minimum values were observed at the start and end of the grazing seasons. Analysis of mean values (Table 3) showed that in both years ADG were greater on light use pastures and were predominant in field MG, while GH were higher on heavy use pastures and were predominant in field HG. Mean ADG and GH were greater in 2009 versus 2008 for both MG and HG treatments.

In addition, ADG were similar between LG and MG treatments over the two years (Figure 2). SR did not influence ADG in the initial month of 2008 (P>0.05) (Table 3). However, ADG tended to decrease linearly (P<0.01) as SR increased, with the difference numerically greater between VHG versus MG and HG than between MG and HG. ADG in field VHG were the smallest (P<0.05) during the whole grazing period, and the goats began losing weight (-24.1 g goat^{-1} day^{-1}) in the final month of 2009. In contrast to production per goat, the effects of SR on GH were not noticeable in the initial months of both years (P>0.05) (Table 3). However, weight gains per hectare increased as SR increased from fields LG to MG and HG, but then decreased with further increase in SR (P<0.01) after the initial months. Moreover, as SR increased from 7.5 to 15, 7.5 to 30 and 7.5 to 45 goats ha^{-1}, mean GH increased by 50.4, 70.4 and 51.6% in 2008 and 54.6, 72.0 and 47.7% in 2009, respectively.

Regression relationships

ADG of grazed goats declined linearly as SR increased in both years (Figure 4); the slope was steeper for 2009 (r = –0.572, P = 0.001) than for 2008 (r = –0.505, P<0.01). Although changes in ADG were similar in each year, ADG values tended to be greater in 2009 versus 2008. Figure 5 also illustrates the relationship between ADG and SC with regression analysis in each year. ADG increased linearly as SC increased, and the slope of the regression line was highly significant in both 2008 (r = 0.811, P<0.001) and 2009 (r = 0.753, P<0.001). The relationships between SR and ADG, and SC and ADG were explored based on monthly data obtained in each year. The optimal SR at which maximum GH and maximum SC occurred was estimated by calculating equations derived from the relationships between SR and SC, and SR and GH. Since the tendency over the two years was consistent, subsequent analyses were

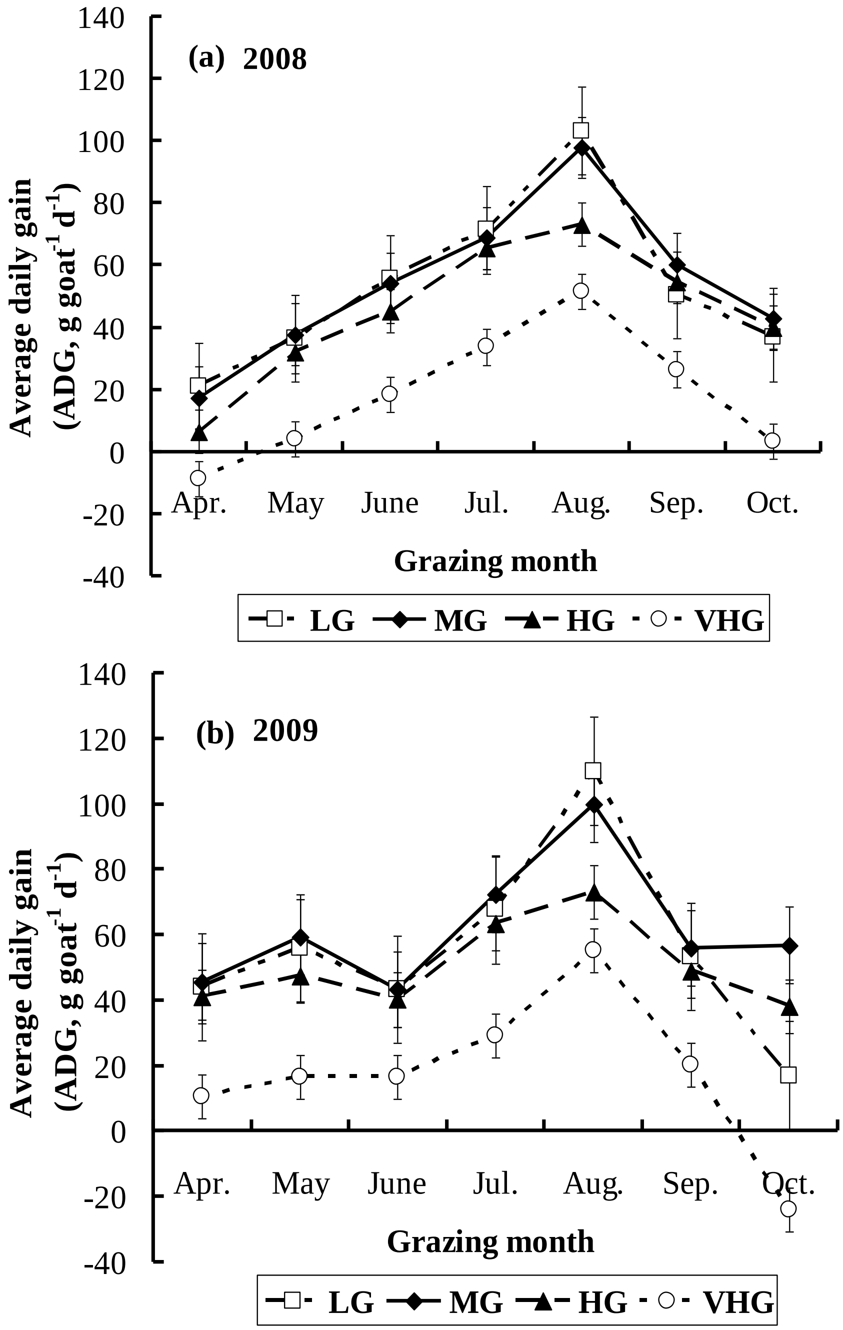


Figure 2. Effect of stocking rate (SR) on average daily gain (ADG) in 2008 (a) and 2009 (b). The four SRs are LG (light grazing, 7.5 goats ha^{-1}), MG (medium grazing, 15 goats ha^{-1}), HG (high grazing, 30 goats ha^{-1}) and VHG (very high grazing, 45 goats ha^{-1}), respectively. Data are mean ± SE.

conducted based on the overall data obtained in both years. The results (Figure 6) show that SC was best correlated in a negatively linear way with SR (SC′= 0.708 – 0.00753SR, r = –0.645, P<0.001), but GH for goats showed a quadratic trend as SR increased (GH′= 0.050364SR – 0.000865SR^2 – 0.181225, r = 0.528, P = 0.0002).

According to the quadratic equation between GH and SR (Figure 6), the optimum SR (point A) for goats was 29.1 goats ha^{-1}, at which the maximum GH was 41.2 kg ha^{-1}, and the SC was 138.9 g DM m^{-2}. Furthermore, as SR increased, SC twice intersected with GH. Equations 5 to 9 were used to calculate the range of SR, GH and SC. SR that can provide good pasture productivity for goats

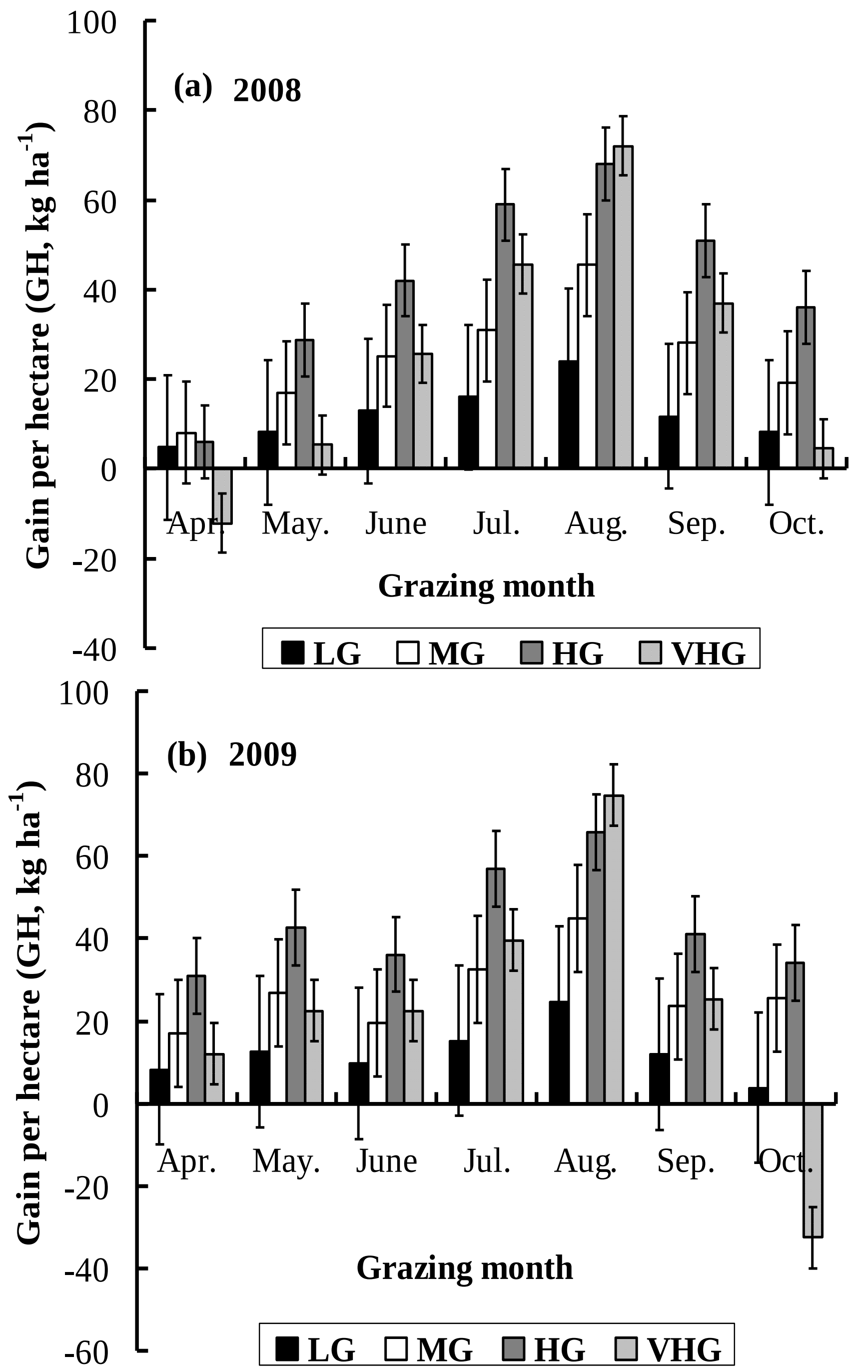


Figure 3. Monthly changes of gain per hectare (GH) on improved pastures set-stocked at 7.5 (LG), 15 (MG), 30 (HG) and 45 (VHG) goats ha^{-1} during year 2008 (a) and 2009 (b). Data are mean ± SE.

ranging from 23.9 (point B) to 43.1 (point C) goats ha^{-1}, at which the gain per hectare ranged from 39.5 to 28.7 kg ha^{-1}, and the level of SC ranged from 150.1 to 109.1 g DM m^{-2}. Obviously, in this experiment, SR at point D showed the same GH value (39.5 kg ha^{-1}) relative to SR at point B. SR at point D was derived from Equations 5 and 7:

GH′ = 39.5/74.7 = 0.528

GH′ = 0.050364SR – 0.000865SR^2 – 0.181225 = 0.5282

Hence, the stocking rate at point D was as follows:

SR = [0.050364+$\sqrt{(0.050364)^2 - 4 \times 0.000865 \times 0.709}$] / (2 × 0.000865)

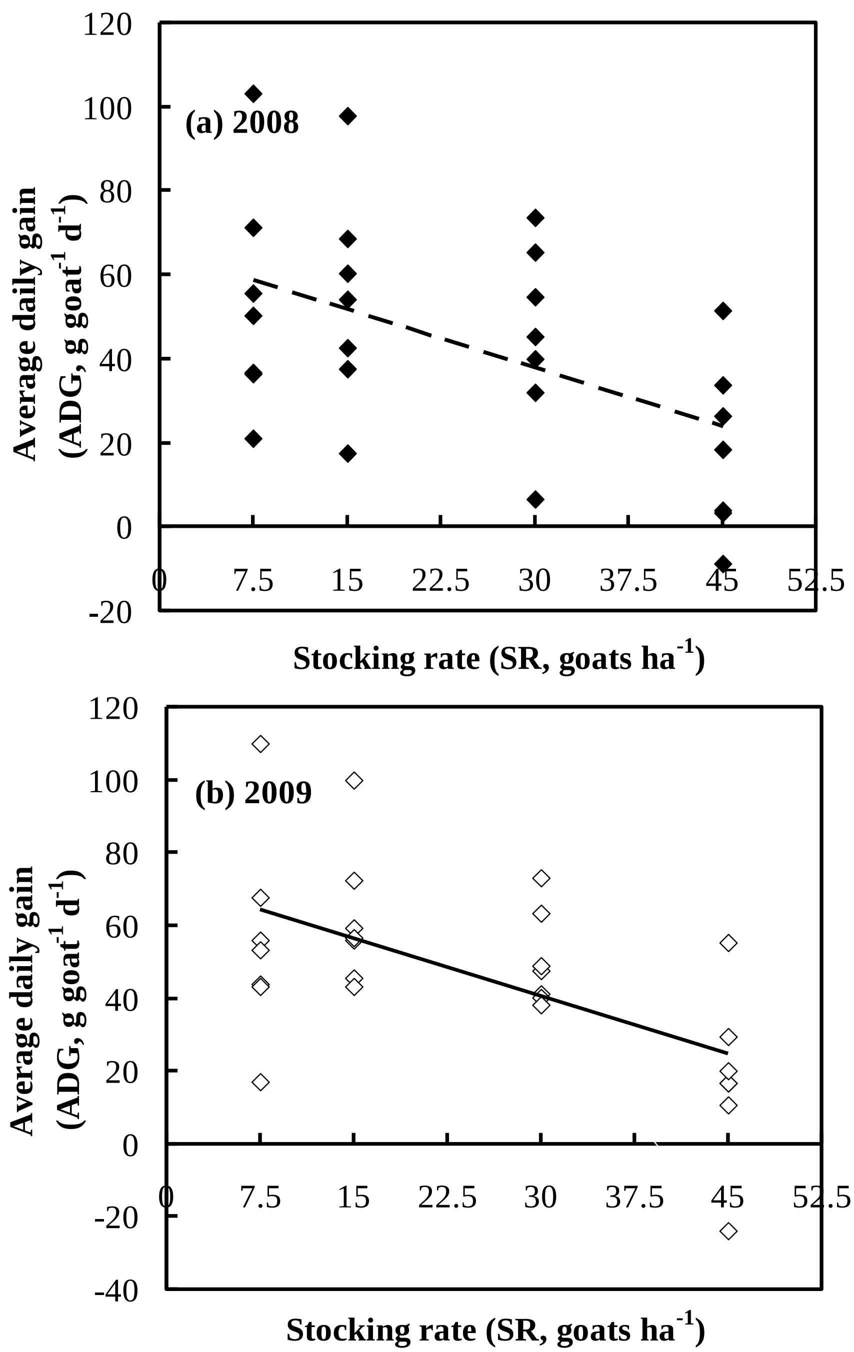


Figure 4. Relationship between SR and ADG by grazing goats in 2008 (◆) and 2009 (◇). Equations: ADG 2008 [g goat^{-1}day^{-1} = 65.597 – 0.934SR; ADG 2009 [g goat^{-1}day^{-1}] = 72.141 – 1.052SR).

SR (point D) = 34.3 goats ha^{-1}

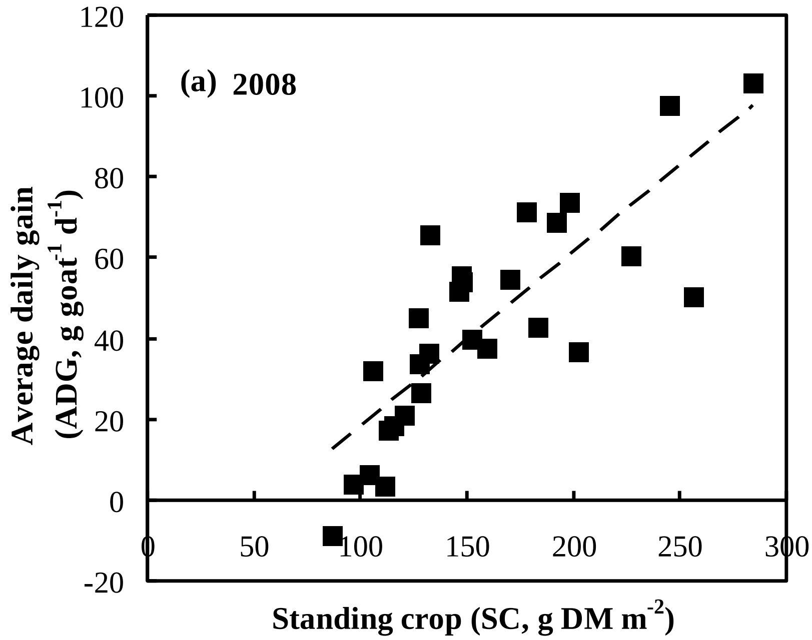
The level of SC at point D was estimated by substituting the SR value (34.3 goats ha^{-1}) back into Equations 8 and 6:

SC′ = 0.708 – 0.00753 × 34.3 = 0.4497

SC (point D) = 0.4497 × 284.11 = 127.8 g DM m^{-2}

DISCUSSION

A low-high-low growth trend for SC was observed during the grazing period across spring, summer and autumn,



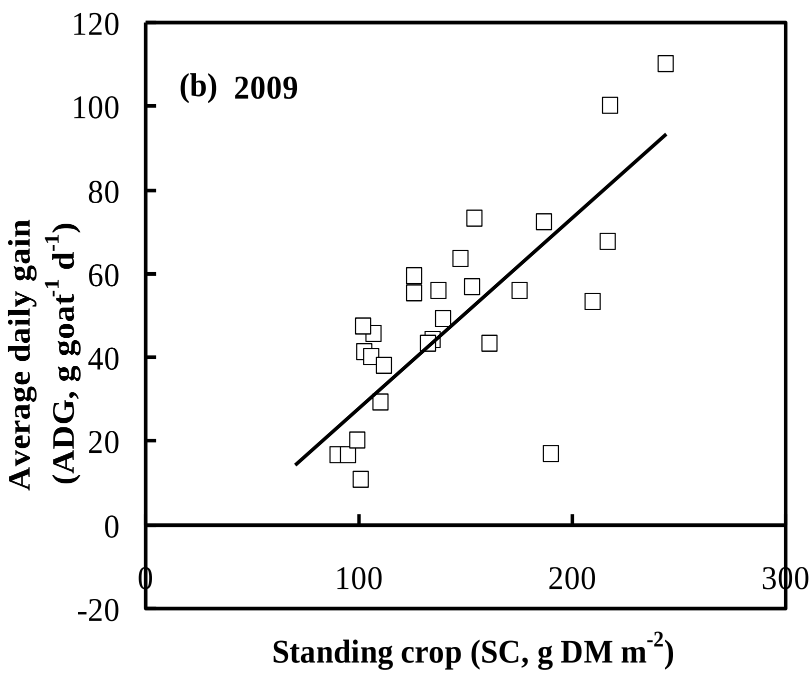


Figure 5. Positive linear relationship between ADG and standing crop (SC, g DM m^{-2}) in 2008 (a, ■) and 2009 (b, □). (Equations: ADG 2008 [g $goat^{-1}day^{-1}$] = 0.4311SC – 24.747; ADG 2009 [g $goat^{-1}day^{-1}$] = 0.4532SC – 17.457).

and the seasonal forage production was found for all four treatments (Table 2). Forage production was mostly related to precipitation (Holst et al., 2006). In year 2008, precipitation in spring (March to May) was 183.2 mm, in summer (June to August) was 576.7 mm, and in autumn (September to November) was 170.8 mm. Similarly, in year 2009, March to May precipitation was 81.9 mm, June to August precipitation was 463.2 mm, and September to November precipitation was 63.2 mm (Figure 1). During the two-year grazing period, herbage productivity was higher in summer, which was related to the higher amount of rainfall received. Interestingly, in both years, SC within all stocking rates reached a peak in August, which coincided with the highest precipitation rate of 201.4 mm in August 2008, whereas in 2009 precipitation, rate peaked at 239.7 mm in June. This

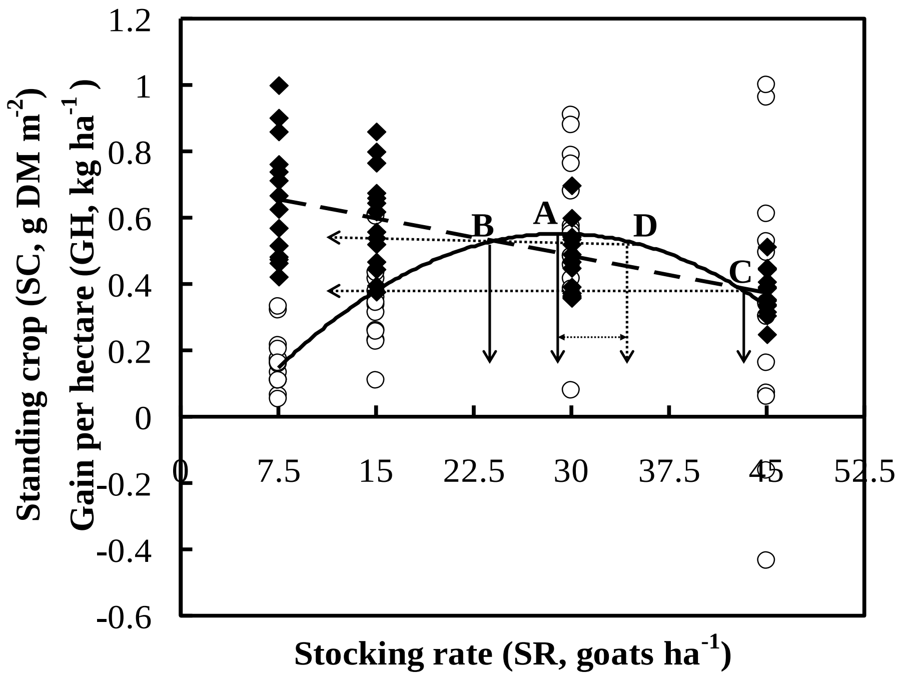


Figure 6. Relationships between SR and SC, and SR and GH during the two-year grazing period. (Equations: SC′ (◆) = 0.708 – 0.00753SR; GH′ (○) = 0.050364SR – 0.000865SR^2 – 0.181225).

observation may indicate that June precipitation was sufficient to maintain higher forage production. In other researches, July precipitation on a Rough Fescue Grassland (Willms et al., 1986), or precipitation occurring before August on a Mixed Prairie (Smoliak, 1986) was important for maintaining forage production. Furthermore, Dong et al. (2006) found that on *Elymus nutans/Puccinellia tenuflora* mixed-sown pasture in Yangtze and Yellow river headwater regions, the maximum SC appeared one month earlier in heavy grazing intensity than in light grazing intensity. This may only be caused by local environment and species composition. Similarly, greater forage growth for all four treatments in 2008 compared with 2009 were likely because of the greater annual rainfall observed in 2008 (Figure 1).

Over both years, mean SC values were similar in field LG, and no significant differences for seasonal SC values were found between treatment LG and MG (Table 2), suggesting that herbage productivity was quite stable at light grazing intensity. The same was observed by Willms et al. (1986) with cattle grazing at four SR (1.2, 1.6, 2.4, and 4.8 AUM ha^{-1}) in western Canada. There was no SR effect on SC in the initial sampling months of each year (Table 2), which seems to indicate that winter recovery was sufficient to maintain herbage productivity. During the grazing period, however, SR effects were evident as the season progressed, especially in the second year. Standing crop declined linearly with SR increasing on mixed perennial ryegrass-white clover-cocksfoot pastures (Table 2 and Figure 6), and the linear equation relating SR to SC were also developed by Bransby et al. (1988) with steers under continuous grazing at four grazing pressures over three consecutive years. Stocking at 45 goats ha^{-1} (VHG) resulted in a serious decline in SC compared with the other three grazing treatments.

The relationship between gain per animal and SR has been widely discussed, and different opinions have co-existed for decades (Hart, 1993). For example, Mott (1960) concentrated on a modified exponential function as a general expression of the relationship between gain per animal and SR, and Connolly (1976) contended that ADG decreased with a hyperbolic model as SR increased. However, the linear relationship between ADG and SR revealed in this study corroborates the model proposed by others (Hart, 1972; Jones and Sandland, 1974; Bransby, 1984). Most of these studies concentrate on relating animal growth to SR; few have considered the relationship between SR and SC (Bransby et al., 1988). In this experiment, ADG and GH values also followed the same seasonal changes as SC (Figures 2 and 3). Mean SC on pastures were greater ($P<0.05$) at 7.5 and 15 goats ha^{-1} than at the 30 and 45 goats ha^{-1} in both years (Table 2). Likewise, mean ADG of goats were higher with the 7.5 and 15 than with the 30 and 45 goats ha^{-1} SR (Table 3). These results suggest that pasture productivity is always the major limiting factor for livestock production (Schlegel et al., 2000), especially on improved pastures that have larger carrying capacities (Bransby et al., 1988). Based on our experimental data, the relationships between ADG and SC were well described by linear functions. The result seems to validate the assumption provided by Bransby et al. (1988), who suggested the use of separate linear regressions to relate ADG to SR, ADG to SC, and SR to SC for different improved pastures.

In contrast to the linear relationship between ADG and SR, the corresponding relationship between gain per hectare and SR was curvilinear (Figure 6). This is the reason that we could not achieve maximum ADG and GH values at a same SR, as described by previous studies (Petersen et al., 1965). Most reports postulated a curvilinear relationship between GH and SR (Hart, 1972; Jones and Sandland, 1974; Bransby et al., 1988). This assumption appears to be confirmed by our quadratic equation result from the goat grazing trials. Based on observations of Sharrow et al. (1981), the low gain of individual animals was more than compensated for by large animal numbers present at higher SR. Ackerman et al. (2001) also reported that decreased gain per animal is always compensated by increased gain per hectare. However, in the current study, GH increased from 7.5 to 30 goats ha^{-1} SR and declined at 45 goats ha^{-1} SR during each year (Figure 3). This result is consistent with the findings of Mott (1960) and Riewe (1961), who reported that decreased gain per hectare was presented at very high SR. Therefore, this experiment suggests that SR exceeded the potential for increased gain at 45 goats ha^{-1} on improved pastures.

In terms of these models (Jones and Sandland, 1974; Bransby et al., 1988), maximum GH was tested at point A, where optimum SR was 29.1 goats ha^{-1} and pasture utilization rate remained at 63.1%. A similar analysis for Jiang and Li (1993) indicates an optimum pasture utilization rate of 60% on high plateau mixed sown pastures of China. In our calculations, it is evident that pasture utilization rate at point B (51.8%) and point C (76.6%) are the lower limit and upper limit, respectively, for goats grazing on improved pastures. In this area, pasture outputs are sustainable to support pasture renewal and goat production. This is in agreement with the observation of Wa et al. (1994), who reported that the range of herbage mass to maintain sheep production was between 1100 to1600 kg DM ha^{-1}. For choosing optimum stocking rate range, some scholars suggest a 50% utilization rate principle (Xu, 1985), but it is best used on natural grassland, and will result in herbage resource waste on improved pastures. Clearly, the target of 50% pasture utilization rate is misleading; there is some room to improve utilization rate on improved pastures. At one time, it was pointed out that SR is a key profit driver for pasture utilization; increasing SR by 5% will increase profits by at least 10% (Zell, 2005). Thus, point B with the same GH value (39.5 kg ha^{-1}) was estimated at point D, which was close to maximum GH value at point A (Figure 6). SR at point D was 1.2 and 1.4 times higher than at points A and B, respectively, and the pasture utilization rate was increased to 74.3%. It can be seen that setting SR between 29.1 and 34.3 goats ha^{-1} may achieve greater gains per hectare with acceptable levels of variability and long-term pasture sustainability. On the other hand, increasing SR above 34.3 goats ha^{-1} decreased SC and gain per hectare, and improved pastures may suffer degradation after several years. Overall, the optimum pasture utilization rate recommended based on the results of this trial ranged from 63.1 to 74.3% and this result is consistent with Hu (1992), who proposed a pasture utilization of 65 to 70% in the mountains of the sub-tropical region in southern China.

In conclusion, both pasture productivity and goat production were considered in this study. It is likely that the regression models of the grazing trials will provide reference for similar pastures and production environments. Further experiments addressing other limiting factors involved in the pasture management also need to be performed in the interest of optimizing livestock production systems.

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