Short running title: Goat grazing in abandoned fields

Sustainable goat grazing for managing abandoned fields: dynamics of vegetation quality, quantity and nutritional status of goats over five years

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Abstract

Grazing goats have potential for use in managing abandoned fields. However, it is unclear how long-term grazing affects goats as a result of vegetational changes in abandoned fields. This study aimed to assess the dynamics of vegetation quality and quantity and the nutritional status of goats for five years in an abandoned field at different stocking rates: high stocking rate (HS: 30–33 goats ha^{-1}) and low stocking rate (LS: 14 goats ha^{-1}). In five years, the dominant plant species changed from bamboo (*Phyllostachys edulis*) to tufted grass species at the HS, whereas dwarf bamboo (*Pleioblastus argenteostriatus*) dominated throughout the five years at the LS. The annual plant biomass at both stocking rates was similar and varied from year to year. Crude protein content in the goats' diet did not show any seasonal or annual trend regardless of the stocking rate. Neutral detergent fiber content in the HS diet did not show any seasonal or annual trend; however, that in the LS diet linearly increased with the grazing year. The dry matter (DM) intake for goats at the LS decreased linearly with the grazing year ($P < 0.05$), whereas that for goats at the HS did not show any trend. The DM digestibility was higher for goats at the HS than for goats at the LS ($P < 0.05$). Serum parameters did not show a negative nutritional status of the goats over the study years. Annual daily gain was positive throughout the grazing years regardless of the stocking rate. Consequently, within the stocking rate range studied here, long-term goat grazing changes the quality of vegetation in an abandoned field; however, goats can maintain their nutritional status and body weight for five years. Thus, goat grazing is a feasible way to control abandoned vegetation over the long term.

Keywords

Abandoned field; goat grazing; nutrition; stocking rate; sustainable management.

Introduction

The number of abandoned fields has been increasing over the last four decades in developed countries (MacDonald et al. 2000; Cramer et al. 2008). In European countries and Japan, agricultural intensification and socioeconomic changes have generated many abandoned fields in marginal agricultural areas (MacDonald et al. 2000; Katayama et al. 2015). Currently, the area of abandoned agricultural fields is over 400,000 ha in Japan (MAFF 2017), and globally, the area of abandoned fields is estimated to be from 385 to 472 million ha (Campbell et al. 2008).

In warm and wet climate areas, inadequate or poor field management leads to invasion and overgrowth of weedy plants, and this often results in field degradation. Thus, an increase in the area of abandoned fields induces the degradation of rural landscapes (MacDonald et al. 2000; Fukamachi et al. 2001) and the risk of wildfire (Osoro et al. 2007). Therefore, appropriate, cost-effective and labor-saving management should be implemented to conserve these field environments.

Grazing could be a powerful tool for conducting this type of weed and field management. Goats may be effective in weed management because they prefer shrubby and woody plants, unlike cattle and sheep (Celaya et al. 2007a; Ferreira et al. 2013). Goats can survive in nutritionally harsh environments due to their ability to feed on a wide range of plants and their low metabolic requirements (Lu 1988; Silanikove 2000). They are also suitable for hilly and mountainous environments in marginal agricultural areas. Thus, some countries use goats to control weedy plants (Popay and Field 1996; Celaya et al. 2010; Narvaez et al. 2012).

Generally, abandoned fields are composed of seminatural vegetation that often contains fewer nutrients than sown grasses, and their botanical composition differs among regions and management regimens (Celaya et al. 2007b). For example, European heathland communities consist of poor-quality herbaceous plants (Celaya et al. 2007a; Osoro et al. 2007); thus, such field conditions limit the use of sustainable goat grazing systems (Osoro et al. 2013). In contrast, Japanese abandoned vegetation is composed of a variety of plant species, such as grasses, sedges, legumes and forbs, and contains more than 50% total digestible nutrients (TDN) and 8% crude protein (CP) (Tsutsumi et al. 2009). These values would meet the recommendations of the NRC (2007) (more than 50% TDN and 7% CP) for the maintenance of goats. However, there is little information about whether such abandoned vegetation can support a sustainable goat grazing system over many years.

In grazing, the stocking rate is the primary factor that affects vegetation dynamics (Celaya et al. 2010) and animal performance. Askar et al. (2013) revealed that a plant biomass of more than 1,400 kg DM ha^{-1} did not restrict the performance of grazing goats regardless of stocking rate in a grass/forb pasture. However, their study was carried out in a sown pasture, and the results may not apply to abandoned fields because the quantity and quality of the vegetation in abandoned fields are different from those in sown pastures. Moreover, long-term grazing with different stocking rates alters plant biomass and botanical composition (Marriott et al. 2005; Celaya et al. 2010). Marriott et al. (2005) found a decrease in quantity and quality of forage with extensive grazing management over five years. Thus, vegetation changes that occur at an inappropriate stocking rate may hamper the use of sustainable grazing in the management of abandoned fields

Therefore, understanding these dynamics will help in the use of sustainable goat grazing systems to control abandoned agricultural land in a hilly area. The objective of the present study was to evaluate the quantitative and qualitative dynamics of vegetation, nutrient intake and goat performance in response to different stocking rates over a 5-year period and to determine a stocking rate at which goats are fed throughout the season only by grazing in abandoned fields.

Materials and methods

All animal experimental procedures were approved by the Committee for Animal Research and Welfare of Gifu University (#13022, 15020 and 17034) and were conducted in accordance with the guidelines of animal research and welfare of Gifu University.

Study site and experimental design

The experiment was conducted from 2013 to 2017 in an abandoned field (0.8 ha) in Minokamo City, Gifu, central Japan (35°29’ N, 137°1’ E, alt. 130 m). The average temperature and annual precipitation were 15.3 °C and 1841 mm, respectively, during the experimental years. The soil type in this region is brown forest soil based on volcanic sediments. Approximately one-fourth of the study site was composed of flat terrain, and the remaining area was hilly. The average gradient in the hilly part was 30 degrees. The site had been used for cultivation in the past, but after the site was abandoned, invading plant species, mainly bamboo (*Phyllostachys edulis*), dominated the site for many years. Before the start of this experiment (March 2012), the bamboo was clear cut.

The experimental site was divided into two areas (0.3 and 0.5 ha), and 16-17 Shiba×Saanen crossbreed goats (initial mean body weight (BW): 26.3 ± 8.0 kg in 2013, 31.1 ± 7.0 kg in 2014, 27.2 ± 7.7 kg in 2015, 26.6 ± 8.3 kg in 2016 and 26.8 ± 9.3 kg in 2017) were assigned to the areas at two different stocking rates: nine goats (2013-2016, 2017) or ten goats (5th year) represented a high stocking rate (HS: 30 or 33 goats ha^{-1}), and seven goats represented a low stocking rate (LS: 14 goats ha^{-1}). The goats were stocked in the areas from May or June to October or November for five years (from 2013 to 2017). The grazing days were 146, 170, 165, 161 and 140 days in 2013, 2014, 2015, 2016 and 2017, respectively A wooden shelter (3.6 m × 1.8 m × 1.8 m) was set before the commencement of this study in each paddock. Animals had free access to mineral mixture and water tanks, and the water was replaced every morning during the grazing period.

Vegetation and animal measurements

Animal and vegetation measurements were conducted in the spring, summer and autumn, and each investigation period consisted of two weeks. In 2014–2017, the investigation dates were in spring (late May), summer (late July) and autumn (mid-September–early October), but those in 2013 were one month later because the beginning of the goat grazing was delayed by one month.

Botanical composition was measured at 20 fixed plots at each stocking rate during each investigation period using 25 cm × 25 cm quadrats. The plant species in the quadrats were identified, and classified into six plant groups: forbs, grasses, Cyperaceae, shrubs, bamboo and dwarf bamboo (*Pleioblastus argenteostriatus*). Then, the cover of each plant group in the quadrat was measured.

Plant biomass at each stocking rate was measured during each investigation period using 50 cm × 50 cm quadrats. Six quadrats were randomly placed in each area, and plants within a quadrat were cut at ground level and weighed. The plants were divided into edible and non-edible parts. Approximately 200 g of the edible samples were collected, dried at 60 °C for 48 h and ground through a 1-mm screen using a Wiley mill. Dried samples were kept at room temperature until chemical analysis.

Forage intake by the goats was measured using a double-indicator method with *n*-alkane as an external indicator (Mayes et al. 1986) and acid detergent insoluble ash (ADIA) as an internal indicator (Nakano et al. 2007). *n*-Alkane capsules that included 0.25 mL of dotriacontane (C_{32}) solution were prepared. Each *n*-alkane capsule (C_{32}) was administered with a small amount of concentrate to five mature goats in each stocking rate treatment at 9:00 am and 4:00 pm every day during the investigation periods. Fecal grab samples were collected from the rectum of these goats twice a day during the final week of each investigation period. Approximately 10 g of morning and evening fecal samples from each goat were well mixed and frozen at -30 °C and then freezedried and milled through a 1-mm screen using a Wiley mill.

To estimate dietary components and *n*-alkane contents of the diets, we observed the foraging behavior of four goats that were used for intake measurements. The behavioral observations were conducted over two successive days during each investigation period. On each day, two goats in each stocking rate treatment were observed by trained observers for two hours during the morning and afternoon feeding bouts. The observers continuously counted the number of bites for each plant species. Then, the top 9-10 plant species in the bites (approximately 80-90% of the total number of bites) were collected by mimicking goats' feeding behavior. Approximately 150 g of each plant species that was ingested by the goats was imitatively collected by hand clipping. The plant samples were frozen at -30 °C and then freeze dried and milled through a 1-mm screen using a Wiley mill. The diet samples were prepared by mixing each ground plant sample according to the proportion of each plant in the bites.

Blood sampling was carried out at 10:00 am on the final day of each period. Blood samples (20 mL) were collected from the jugular vein of the five goats that were used for intake measurements. Blood samples were immediately placed on ice and centrifuged at 1,000×*g* at 4 °C for 20 min. Serum was separated and frozen at -30 °C until analysis.

The goats were weighed on the first and last days of each investigation period.

Chemical analyses

Plant biomass, diet and fecal samples were analyzed for dry matter (DM), CP and crude ash (CA) content according to the Association of Official Analytical Chemists procedures (AOAC 2007). Neutral detergent fiber (aNDFom) was assayed with heat-resistant amylase and ash, acid detergent fiber was expressed exclusive from residual ash (ADFom) and ADIA contents were determined according to Van Soest et al. (1991).

The contents of *n*-alkane (C_{32}) in fecal samples were measured according to the method of Dove and Mayes (2006) using gas chromatography (GC) with a flame ionization detector. The GC sample analysis used a capillary column (TC Series TC-1, 30 mm × 250 μm diameter, GL Sciences, Tokyo, Japan). The GC system was set at an injector and detector temperature of 350 °C. The GC oven program included an initial temperature of 200 °C, which was held for 0.5 min, and according to the program, the temperature then changed by 20 °C min^{-1} to 250 °C , 10 °C min^{-1} to 300 °C, 6 °C min^{-1} to 324 °C and 3 °C min^{-1} to 350 °C, and the system was then held at this final temperature for 2 min.

Serum glucose, total cholesterol (TCHO), urea nitrogen (UN), total calcium (Ca), magnesium (Mg) and inorganic phosphate (IP) contents were analyzed using the Dry-Chemistry system (DRI-CHEM 4000V, Fujifilm Medical, Tokyo, Japan) in the first year of the study and using a Discrete Automated Clinical Chemistry Analyzer (Accute TBA-40FR, Canon Medical Systems, Tochigi, Japan) in the other years.

Estimation of fecal output, plant digestibility and dietary intake

Fecal output, plant digestibility and daily dietary intake were estimated using the following equations (Dove and Mayes 2006):

Fecal output (kg DM day^{-1}) = C_{32} dose rate (mg day^{-1})/C_{32} fecal concentration (mg kg DM^{-1})

Digestibility (%) = (1 - (ADIA g kg DM^{-1} in diet)/(ADIA g kg DM^{-1} in feces))×100

DM intake (kg DM day^{-1}) = (fecal output [kg DM day^{-1}]/(1 - digestibility)

Statistical analysis

Plant intake and digestibility, daily gain (DG) and serum blood components were analyzed using a generalized linear mixed model. Fixed effects were stocking rate, season, year and their interactions. Individual variation among goats was considered as a random effect. The statistical procedures were performed using the lmerTest package (Kuznetsova et al. 2014) in R software (ver. 3.0.2.) (R Core Team 2013). If the effect of season and year were significant (P<0.05), orthogonal contrasts were performed.

Results

Botanical composition and plant biomass

Bare ground and litter gradually disappeared with the progression of the grazing years in both treatments (Table 1). The cover of the forb group was the highest in both treatments throughout the five years. Similarly, the cover of grasses in the LS treatment modestly increased, but dwarf bamboo maintained its cover at approximately 15–20% during the five years.

The annual plant biomass at both stocking rates was similar for five years (Table 2), although the biomass at the beginning of the experiment (spring in 2013) was different between the two treatments (HS: 4.9 t DM ha^{-1}; LS: 3.5 t DM ha^{-1}). Plant biomass decreased with the progress of seasons at both stocking rates. In brief, the average plant biomass in spring was approximately 3 t DM ha^{-1} (HS: 3.3 and LS: 2.8 t DM ha^{-1}), but biomass fell below 2 t DM ha^{-1} in autumn (HS: 1.8 and LS: 1.6 t DM ha^{-1}). Plant biomass varied from year to year. In the HS treatment, the biomass in the first year showed the highest value, decreased in the second year and then gradually increased in the remaining years. In the LS treatment, the biomass was highest in the first year and dropped below 2.0 t DM ha^{-1} in the other years, except for the fourth year.

Diet compositions

The goats in both treatments mainly bit the forbs during the first year of grazing, but this tendency gradually decreased with the progress of the grazing years (Table 3). In HS goats, percentage of bites of grasses and bamboos increased over five years, whereas in LS goats, that of bamboo and dwarf bamboo increased over the period.

Chemical compositions of diets

The CP content in the HS diet decreased from spring to summer (14.3 to 13.2%) and then increased again in autumn (15.0%) (Table 4). However, the CP content in the LS diet linearly increased from spring to autumn (12.6 to 13.6%). The aNDFom content in the HS diet increased from spring to summer (45.1 to 54.5%) and decreased in autumn (51.6%), whereas that of the LS diet increased from spring to autumn

(54.1 to 57.0%). The ADIA content of diets in both treatments linearly increased with the progression of seasons (HS: 2.4 to 6.5% and LS: 3.3 to 8.8%).

The CP content in the HS diet was higher than in the LS diet (14.2 and 13.1%, respectively), and the aNDFom and ADIA contents were higher in the LS diet (aNDFom: 55.4 and ADIA: 5.8%) than in the HS diet (aNDFom: 50.4 and ADIA: 4.7%).

The CP content did not show any annual trend and varied from 12.4 to 15.8% in the HS diet and from 12.4 to 14.1% in the LS diet. The aNDFom content in the HS diet also showed no annual trend (44.0 to 55.6%), whereas that in the LS diet linearly increased from the first to fifth year (51.1 to 60.8%). The ADIA content in the HS diet was between 4.3 and 5.1% and was almost constant over the five years. In the LS diet, the ADIA content showed an increasing trend from the first to the fifth year (4.8 to 6.2%).

Daily gain

The average DG of the grazing goats did not differ between the stocking rate treatments; DG was 7.0 g day^{-1} in the HS treatment and 16.6 g day^{-1} in the LS treatment (Table 5).

Season significantly and quadratically ($P < 0.05$) affected DG at both stocking rates; that is, DG was lower in summer (HS: -39.4 and LS: 12.8 g day^{-1}) than in other seasons (spring, HS: 58.4 and LS: 67.4 g day^{-1}; autumn, HS: 65.8 and LS: 44.3 g day^{-1}). However, annual DG was positive regardless of the stocking rate and was not significantly affected by year (Table 5).

Intake

Stocking rate did not affect DM, CP or aNDFom intake (Table 5). In contrast, DM intake was significantly affected by season and by the stocking rate × season interaction (season: $P < 0.05$, stocking rate × season: $P < 0.05$). The average DM intake for goats at the HS was 83.8 g/kg BW$^{0.75}$ in spring but decreased with season (Figure 1, linear response: $P < 0.05$), while the goats at the LS showed higher DM intake in summer than in spring and autumn (Figure 1, quadratic response: $P < 0.05$). Season also affected aNDFom intake (quadratic response: $P < 0.05$). The aNDFom intake at both stocking rates ranged from 36.7 to 44.6 g/kg BW$^{0.75}$ and was higher in summer than in spring and autumn (quadratic response: $P < 0.05$). Season did not affect CP intake at either stocking rate, but the stocking rate × season interaction significantly affected CP intake (P < 0.05). Specifically, CP intake for goats at the HS was relatively constant throughout the grazing season, whereas their CP intake at the LS showed higher values in summer than in spring and autumn (Figure 1, quadratic response: P < 0.05).

The DM, CP and aNDFom intake at both stocking rates was significantly different among grazing years (P<0.05). The DM intake at both stocking rates was highest in the second year and lowest in the last year (Figure 2). For goats at the LS, DM intake decreased with year (Figure 2, linear response: P < 0.05), while that of goats at the HS did not show any trend. The CP intake at both stocking rates varied from 6.9 to 13.6 g/kg $BW^{0.75}$ (Table 5) among the years. The CP intake for goats at the LS was highest in the second year and lowest in the fifth year (Figure 2. quadratic response, P < 0.05). For goats at the HS, CP intake was almost constant throughout grazing years. The aNDFom intake for goats at the HS showed a quadratic response with grazing years (Figure 2, P < 0.05), while aNDFom intake for goats at the LS decreased linearly with grazing years (P < 0.05).

Digestibility

The DM and aNDFom digestibility significantly differed between the stocking rates ($P < 0.05$). The DM digestibility was higher in goats at the HS (53.8%) than in goats at the LS (45.3%), and aNDFom digestibility was also higher in goats at the HS (49.7%) than in goats at the LS (43.4%). Stocking rate did not show any significant effect on CP intake.

Season significantly affected DM, CP and aNDFom digestibility (DM: $P < 0.05$, CP: $P < 0.05$, aNDFom: $P < 0.05$) (Table 5). DM digestibility in goats at the HS decreased from 61.4% in spring to 46.7% in autumn (linear response: $P < 0.05$) (Figure 1), whereas goats in the LS treatment showed higher DM digestibility in summer (52.0%) than in spring and autumn (49.0 and 33.4%; quadratic response: $P < 0.05$). Seasonal changes in CP digestibility showed a trend similar to that of DM digestibility at both stocking rates, but there was no significant seasonal effect on CP digestibility in goats at the HS (Figure 1). The aNDFom digestibility was the highest in summer (HS: 52.8 and LS: 50.7%) and the lowest in autumn (HS: 45.8 and LS: 35.1%) at both stocking rates (Figure 1). The aNDFom digestibility in goats at the LS showed a quadratic response ($P < 0.05$) (Figure 1), while no significant trend was detected in goats at the HS.

There was no effect of year on DM digestibility, but year significantly affected CP and aNDFom digestibility (CP: $P < 0.05$, aNDFom: $P < 0.05$) (Table 5). aNDFom digestibility showed a quadratic response regardless of stocking rate (quadratic response: $P < 0.05$) (Figure 3). There was a significant difference in CP digestibility among the years, with no linear or quadratic changes detected at both stocking rates (Table 5 and Figure 2). Annual aNDFom digestibility at both stocking rates showed a quadratic response according to year (quadratic response: HS, $P<0.05$; LS, $P < 0.05$) (Table 5 and Figure 2).

Serum blood components

Stocking rate did not affect blood components except for Mg (Table 5). The Mg concentration was higher in goats at the HS (3.0 mg dL^{-1}) than in goats at the LS (2.8 mg dL^{-1}).

A seasonal effect was found on serum glucose, TCHO, UN and Mg concentrations (all: $P < 0.05$); however, there were no significant stocking rate × season interactions for any serum components. Serum glucose concentrations at both stocking rates were lower in summer than in spring and autumn (quadratic response: $P < 0.05$) (Figure 3). Although there were significant differences in serum TCHO concentrations among seasons, differences were not as great throughout the gazing seasons (Figure 3). Serum UN concentrations in the grazing goats increased linearly from 17.0 to 22.9 mg dL^{-1} regardless of the stocking rate (Figure 3). Serum Mg concentrations increased from 2.8 to 3.0 mg dL^{-1} with the progression of seasons in goats at the HS ($P < 0.05$) (Figure 3), whereas that in goats at the LS did not show any significant change with season. Season did not affect serum Ca and IP concentrations at either stocking rate (Ca: 9.1 to 9.2 mg dL^{-1} at the HS and LS; IP: 5.5 to 6.0 mg dL^{-1} at the HS and 6.5 to 6.7 mg dL^{-1} at the LS) (Table 5 and Figure 3).

With respect to the effect of years, a significant difference was found in serum glucose, UN, Ca and Mg concentrations (all: $P < 0.05$) (Table 5), and a significant stocking rate × year interaction was detected for serum glucose concentration ($P < 0.05$). Serum glucose concentrations in the goats at the HS were relatively constant over the five-year period, whereas that in the goats at the LS increased over the grazing years ($P < 0.05$) (Figure 4). Serum UN concentrations decreased linearly in the LS treatment ($P < 0.05$) (Figure 4), and the UN concentration was 22.6 mg dL^{-1} in the first year but was 19.2 mg dL^{-1} in the fifth year. Serum TCHO concentrations did not show any significant change with years (ranging from 83.9 to 89.4 mg dL^{-1}) (Figure 4). Serum Ca concentrations showed a quadratic response and Mg concentrations showed a linear increase with grazing year (Figure 4). Ca concentrations showed the lowest value in the third year, and Mg concentrations increased from 2.9 to 3.1 mg dL^{-1} over the five years. Year did not affect serum IP concentrations at either stocking rate (HS: 5.4 to 6.3 mg dL^{-1}, LS: 6.2 to 7.0 mg dL^{-1} over the five-year period).

Discussion

Stocking rate

The annual stocking rates were 828 and 386 kg ha^{-1} at the HS and LS, respectively. Stocking rate did not affect DM, CP or aNDFom intake or the DG of the goats (Table 5). Generally, stocking rate influences plant biomass in a pasture and forage intake by goats (Animut and Goetsch 2008). In the present study, the plant biomass at both stocking rates was maintained at more than 1,600 kg DM ha^{-1} throughout the grazing seasons.

The CP content was higher than 12% and the aNDFom content was less than 56% in the diets regardless of season and year, suggesting that diets contained moderate nutritive value. Askar et al. (2013) reported that stocking rate did not limit the DG of grazing goats when they grazed on a pasture with 1,400 kg DM ha^{-1} or more of plant biomass and a moderate nutritive value. The present results agree with those previous results, and the presence of sufficient plant biomass at both stocking rates resulted in no restriction on the DG of the goats.

Both DM and aNDFom digestibility were influenced by the stocking rate. These differences were caused by differences in the diet compositions between stocking rate treatments (Table 3). The grasses and bamboo (*Phyllostachys edulis*) in the diet of HS goats increased over five years, while the bamboo and dwarf bamboo in the diet of LS goats increased throughout the experiment (Table 3). The percentage of bites of shrubs, which are often high in NDF and lignin contents (Papachristou and Nastis 1993), in LS goats was also higher than that in HS goats. The differences in diet composition might relate to the chemical composition of the goat's diet. Specifically, the aNDFom and ADFom contents in the diet were greater for goats at the LS (55.4 and 31.9%) than the HS (50.4 and 29.9%). Similarly, ADIA contents in the diets were slightly but unalterably higher for goats at the LS than for goats at the HS. Accordingly, DM and fiber digestibility in goats at the LS were lower than in those at the HS. Thus, the original differences in botanical composition between areas at the different stocking rates induced differences in chemical composition in the diets and resulted in the different digestibilities.

Serum Mg concentration was affected by the stocking rate ($P < 0.05$). Both paddocks included a variety of plant species, and generally, Mg content differed in each plant species (Yoshihara et al. 2013). Thus, different botanical compositions may have contributed to different Mg concentrations in both groups; however, grazing goats at both stocking rates did not show any symptoms of Mg deficiency during the study.

Effects of grazing season

The DM intake for goats at the HS ranged from 66.5 to 83.8 g/kg $BW^{0.75}$ and decreased linearly from spring to autumn. In contrast, intake for the goats at the LS ranged from 68.1 to

82.3 g/kg $BW^{0.75}$ and changed from spring to autumn. According to the NRC feeding standards, mature goats at a BW of 30 kg require 53 g/kg $BW^{0.75}$ of DM intake for maintenance (NRC 2007). Thus, grazing goats at both stocking rates satisfied their maintenance requirements throughout the grazing seasons.

The DM digestibility decreased linearly in goats at the HS and showed an opposite trend in goats at the LS ($P < 0.05$), although digestibility at both stocking rates was the lowest in autumn. Plant maturation involves an increase in indigestible components due to lignification of cell walls (Kozloski et al. 2005). Accordingly, plant digestibility in ruminants decreases with increasing plant maturity. In the present study, the ADIA content of the goats' diet at both stocking rates showed the highest value in autumn. Thus, diet digestibility at both stocking rates had the lowest value in autumn.

Serum glucose and TCHO concentrations are indices of the energy status of ruminants (Ndlovu et al. 2007). In the present study, serum TCHO concentrations in grazing goats were relatively constant during grazing seasons regardless of the stocking rate. Conversely, glucose concentrations decreased in summer at both stocking rates. Ndlovu et al. (2007) reported that heat stress increased body temperature and respiratory rate and resulted in a decrease in blood glucose concentrations in cattle. Several studies have also observed a decrease in glucose concentrations in grazing cattle in summer (Grünwaldt et al. 2005; Mapiye et al. 2010). The results of the present study are consistent with those of the above previous studies. Thus, the decrease in serum glucose concentrations in summer was probably caused by heat stress rather than by insufficient energy intake.

Serum UN concentrations increased from spring to autumn at both stocking rates. The concentrations were influenced by the CP/energy ratio in the diet (Hammond et al. 1994; Karnezos et al. 1994). Increasing serum UN concentrations in grazing goats suggest that CP and energy ratios in the diet were imbalanced with the progress of seasons, even in the vegetation of abandoned fields.

Serum mineral concentrations at both stocking rates were almost constant throughout the grazing seasons, except for serum Mg concentrations in goats at the HS (Figure 3). A simulation study by Yoshihara et al. (2013) suggested that increasing the number of plant species reduces the risk of both excesses and deficiencies in ingested minerals. In the present study, goats ate more than 20 plant species at both stocking rates. Thus, grazing on abandoned fields, which are composed of many plant species, may contribute to stabilizing serum mineral concentrations in goats.

Grazing goats at both stocking rates showed the lowest, and negative, values in average DG in summer, although intake and digestibility in summer were higher than in autumn. Generally, heat stress increases the energy consumption of grazing goats by increasing the respiration rate (Shinde et al. 2002), suggesting that forage species in abandoned fields cannot provide sufficient energy to overcome the increase in energy requirements induced by heat stress. However, such negative impact on nutritional status was only observed in summer, and the annual DG of grazing goats at both stocking rates did not show negative values. These results suggest that the vegetation in abandoned fields in central Japan can support the maintenance requirements of grazing goats throughout the grazing season.

Effects of grazing year

Forage biomass at both stocking rates did not show a decreasing trend with the progress of the grazing year, and its annual variation might be due to annual meteorological conditions. The chemical composition of the diets differed between the stocking rates. In the HS treatment, the values in the diet were relatively constant for five years, whereas the quality of the diet, which was reflected by CP and aNDFom contents, decreased over the 5-year period in the LS treatment. This continuing decrease in diet quality might induce a linear decrease in the DM intake of goats at the LS. However, DG in both groups did not decrease over the five years, suggesting that the vegetation in the abandoned fields can support the maintenance requirements of grazing goats for five years regardless of the stocking rate.

During the five years, serum glucose and TCHO concentrations in grazing goats at both stocking rates did not fall below the hypoglycemic and hypocholesterolemic values in goats (37.8 and 65.8 mg dL^{-1}, respectively; Žubčić 2001). Serum glucose concentrations linearly increased with the grazing year, and the reason for this increase was not clear. Serum UN concentrations showed a decreasing trend with the grazing year ($P < 0.05$), although a significant effect was not detected in the HS treatment. However, serum UN levels were close to 20 mg dL^{-1}, which was the upper limit of standard values (NLBC 2018), suggesting that the energy/protein ratio in the diet was not desirable even in the vegetation of abandoned fields, as is the case in sown grasses.

Serum Ca, IP and Mg concentrations at both stocking rates were relatively stable during the five years; however, serum Ca and Mg concentrations differed among the years. Moreover, all the serum mineral concentrations were within the range of standard values for goats (Kaneko et al. 1997). Mineral concentrations are highly variable among plant species (Ohlson and Staaland 2001), and increasing the number of plant species reduces the risk of excesses and deficiencies of ingested minerals (Yoshihara et al 2013). In the present study, grazing goats ingested more than 40 plant species each year. Consequently, abandoned fields that contain various plant species can provide diets that are suitable for maintaining stable serum mineral concentrations in grazing goats over a period of five years.

Conclusion

Goat grazing over five years changed the botanical composition in an abandoned field. This change in vegetation affected the chemical composition of the diet but did not affect plant biomass over five years. Although DM intake at the LS linearly decreased with grazing year, the overall DG remained positive throughout the grazing years regardless of the stocking rate. Serum parameters at both stocking rates did not indicate a negative nutritional status over the years studied, except for relatively higher UN concentrations. Serum mineral concentrations were relatively stable because grazing goats ingested various plant species in the abandoned field. Thus, within a stocking rate range (14–33 goats ha^{-1}), the use of grazing for the sustainable management of abandoned fields is feasible and does not have negative effects on the nutritional status of goats.

Conflict of interest statement

This research did not receive any specific grants from funding agencies in the public, commercial, or not-for-profit sectors.

Acknowledgments

We appreciate Frusic Ltd. (Pres. Shoji Watanabe) for site and animal management. We also thank Minokamo City for preparing the experimental site. Finally, the authors are grateful to M. Achiha, S. Sakoda, A. Kobayashi, T. Murase and M. Iida for their technical assistance.

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Table 1 Changes in botanical compositions with season and year at different stocking rates

	2013			2014			2015			2016			2017		
Cover (%)†	Spring	Summer	Autumn	Spring	Summer	Autumn	Spring	Summer	Autumn	Spring	Summer	Autumn	Spring	Summer	Autumn
High stocking rate															
Bareground and litter	23.8	44.6	43.3	41.3	40.4	38.0	7.4	20.8	23.5	17.8	21.1	14.1	14.8	19.4	15.6
Forbs	43.8	14.6	24.7	36.2	34.5	43.4	57.1	41.7	48.6	48.7	31.6	42.1	51.2	31.3	39.3
Bamboo	18.8	22.7	14.0	1.7	7.0	3.0	3.7	12.2	3.8	7.9	15.6	9.9	6.9	16.5	11.9
Dwarf bamboo	0.0‡	1.2	0.8	5.0	0.7	1.6	1.3	1.2	1.0	1.0	2.5	2.3	4.9	4.9	3.1
Grasses	4.9	7.0	11.5	10.9	12.3	12.5	26.4	19.5	17.5	16.0	20.8	21.3	18.2	24.1	23.0
Cyperaceae	7.0	8.0	5.0	0.0	4.9	0.8	2.1	2.8	3.5	6.0	6.8	6.3	3.9	2.3	5.6
Shrubs	1.8	1.8	0.8	4.8	0.3	0.8	2.1	1.8	2.1	2.6	1.7	4.0	0.1	1.5	1.5
Low stocking rate															
Bareground and litter	34.1	51.4	51.2	40.1	42.3	42.8	26.0	26.1	24.0	14.5	17.0	18.3	10.3	17.9	22.1
Forbs	29.5	11.0	11.8	35.1	16.4	10.5	32.7	24.8	28.3	32.9	26.9	28.3	32.9	26.9	35.8
Bamboo	7.5	11.5	10.7	0.0	9.0	7.4	6.4	8.7	3.4	7.4	10.8	10.6	2.3	9.6	8.1
Dwarf bamboo	17.0	15.2	11.9	14.5	13.5	16.8	12.9	18.9	15.2	16.7	18.1	13.9	21.5	19.1	18.9
Grasses	2.5	0.8	10.3	6.4	9.8	12.7	17.7	15.7	19.3	20.7	19.5	13.3	16.4	11.7	11.4
Cyperaceae	2.0	5.0	2.0	0.8	5.8	7.3	3.7	4.0	8.0	4.7	4.4	3.7	6.6	9.4	7.5
Shrubs	7.3	5.2	2.0	3.1	3.3	2.5	0.7	1.7	1.8	3.2	3.2	4.4	3.6	3.2	2.2

†Means of all investigation plots (20 points in each treatment).

†Bamboo is *Phyllostachys edulis*, and Dwarf bamboo is *Pleioblastus argenteostriatus*.

‡This value is less than 0.1%.

Table 2 Changes in plant biomass (DM) with season and year at different stocking rates

Item	SR†	Season			Year				
		Spring	Summer	Autumn	2013	2014	2015	2016	2017
Biomass (t DM ha^{-1})	HS	3.3	1.9	1.8	3.0	1.9	2.1	2.3	2.5
	LS	2.8	2.0	1.6	2.6	1.8	1.8	2.5	2.0

†HS: 30 goats per ha; LS: 14 goats per ha.

Table 3 Changes in diet compositions (percentage of bites) of grazing goats with season and year at different stocking rates

Diet composition (%)†	2013 Spring	2013 Summer	2013 Autumn	2014 Spring	2014 Summer	2014 Autumn	2015 Spring	2015 Summer	2015 Autumn	2016 Spring	2016 Summer	2016 Autumn	2017 Spring	2017 Summer	2017 Autumn
High stocking rate															
Forbs	82.5	45.9	43.8	29.7	26.9	23.2	59.2	27.6	6.5	54.2	26.5	30.9	59.6	18.6	15.8
Bamboo	0.1	5.5	25.2	15.9	37.6	19.3	1.5	5.2	14.5	13.4	33.9	24.8	5.7	36.6	33.5
Dwarf bamboo	10.5	1.9	2.0	29.2	15.5	5.0	14.2	13.2	22.4	2.6	1.9	4.6	4.6	9.9	2.0
Grasses	2.3	28.6	17.1	13.1	11.7	36.2	17.1	44.3	52.3	12.4	23.5	24.1	20.8	14.0	31.2
Cyperaceae	2.3	10.6	9.4	8.3	7.8	14.8	7.0	6.8	3.9	4.1	11.9	11.7	5.8	18.1	16.5
Shrubs	2.3	7.5	2.4	3.9	0.5	1.5	1.0	2.9	0.3	13.3	2.2	3.6	3.5	2.8	0.7
Litter	0.0‡	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.4	0.0	0.0	0.3
Low stocking rate															
Forbs	58.2	34.8	14.1	37.3	30.0	19.4	30.1	24.0	21.3	32.8	31.2	20.7	20.0	12.2	9.8
Bamboo	1.0	1.5	4.0	27.6	10.2	19.4	27.9	26.8	40.0	14.7	19.3	28.5	47.0	35.0	29.3
Dwarf bamboo	17.1	2.3	28.3	8.2	0.5	22.0	5.1	9.0	0.6	32.3	22.5	21.4	13.1	29.5	29.4
Grasses	16.6	34.9	27.1	7.7	32.5	11.1	14.4	27.2	20.9	8.3	14.2	14.0	11.1	18.6	19.0
Cyperaceae	1.9	6.9	8.4	3.5	17.7	17.8	8.3	9.6	12.7	9.3	9.8	9.6	1.6	3.4	10.1
Shrubs	5.2	19.5	16.9	15.3	8.7	7.7	13.9	3.3	2.2	2.2	3.0	5.2	6.7	1.3	1.9
Litter	0.0	0.1	2.1	0.4	0.3	2.6	0.3	0.0	2.2	0.4	0.0	0.5	0.5	0.0	0.5

†Bamboo is *Phyllostachys edulis*, and Dwarf bamboo is *Pleioblastus argenteostriatus*.
‡This value is less than 0.1%.

Table 4 Changes in chemical composition in goat's diets with season and year at different stocking rates

Item†	Overall mean	Season			Year				
		Spring	Summer	Autumn	2013	2014	2015	2016	2017
HS									
DM (%)	27.5	27.9	26.3	28.2	26.2	27.0	29.8	27.1	27.5
CP (%)	14.2	14.3	13.2	15.0	15.0	12.4	15.8	14.3	13.3
aNDFom (%)	50.4	45.1	54.5	51.6	44.0	55.6	47.3	53.8	51.1
ADFom (%)	29.9	29.1	31.4	29.3	28.2	31.7	27.0	31.8	30.9
ADIA (%)	4.7	2.4	5.3	6.5	4.5	4.9	4.9	4.3	5.1
CA (%)	11.4	8.9	12.0	13.3	11.8	11.3	11.4	10.9	11.5
LS									
DM (%)	27.5	26.3	25.4	30.7	26.9	26.4	29.7	26.0	28.2
CP (%)	13.1	12.6	13.2	13.6	14.1	13.6	12.6	12.9	12.4
aNDFom (%)	55.4	54.1	55.1	57.0	51.1	53.7	54.7	56.7	60.8
ADFom (%)	31.9	31.2	32.5	31.8	31.8	31.0	30.7	32.7	33.1
ADIA (%)	5.8	3.3	5.3	8.8	4.8	4.9	7.0	5.9	6.2
CA (%)	12.2	9.5	12.5	14.6	12.3	11.9	12.4	12.2	12.2

†DM: Dry matter; CP: Crude protein; aNDFom: Neutral detergent fiber assayed with hieat-stable amylase and expressed exclusiely of residual ash; ADFom: Acid detergent fiber expressed exclusively of residual ash; ADIA: Acid detergent insoluble ash; CA: Crude ash.

Table 5 Changes in daily gain, dietary intake and plant digestibility of each nutrient category and serum blood component in grazing goats at different stocking rates and in different seasons and years

Item	SR†		Season			Year					Significance level				
	HS	LS	Spring	Summer	Autumn	2013	2014	2015	2016	2017	SR	Season	Year	SR×Se	SR×Ye
Daily Gain (g day^{-1})	7.0	16.6	64.4	-17.0	54.6	10.6	13.7	16.5	12.0	5.8	0.179	<0.001	0.764	0.177	0.147
Intake (g/kg $BW^{0.75}$)															
DM	76.8	73.8	75.1	82.3	68.1	73.9	102.6	67.5	80.6	53.1	0.197	0.002	<0.001	0.007	0.304
CP	10.9	9.7	10.1	11.0	9.9	10.8	13.6	9.5	11.1	6.9	0.081	0.061	<0.001	<0.001	0.019
aNDFom	38.8	40.4	36.9	44.6	36.7	35.1	55.7	34.1	44.1	28.8	0.515	<0.001	<0.001	0.154	0.521
Digestibility (%)															
DM	53.8	45.3	55.9	52.2	40.7	46.0	51.2	50.0	53.6	48.9	0.007	<0.001	0.208	<0.001	0.113
CP	59.0	51.3	57.4	56.6	52.1	51.9	52.1	55.9	60.8	56.9	0.172	0.011	0.007	0.001	0.011
aNDFom	49.7	43.4	47.0	51.8	41.0	33.5	48.9	52.1	52.3	47.3	0.003	<0.001	<0.001	0.054	0.048
Serum blood component (mg dL^{-1})															
Glucose	49.0	51.4	50.9	44.5	54.9	50.6	45.2	51.8	46.9	55.4	0.273	<0.001	<0.001	0.238	0.028
Urea Nitrogen	20.5	20.8	17.0	22.2	22.9	22.6	22.1	19.1	20.4	19.2	0.882	<0.001	0.042	0.634	0.893
Total cholesterol	86.9	88.3	84.1	90.7	88.0	89.3	90.5	85.3	89.4	83.9	0.488	0.023	0.446	0.767	0.204
Ca	9.2	9.1	9.2	9.1	9.2	9.5	9.4	8.6	9.1	9.1	0.812	0.352	<0.001	0.564	0.814
IP	5.8	6.6	6.2	6.2	6.1	6.4	6.1	6.3	6.1	6.2	0.364	0.922	0.505	0.556	0.428
Mg	3.0	2.8	2.8	2.8	3.0	2.9	2.4	2.8	3.1	3.1	0.048	<0.001	<0.001	0.668	0.202

†HS: 30 goats per ha; LS: 14 goats per ha.

Figure legends

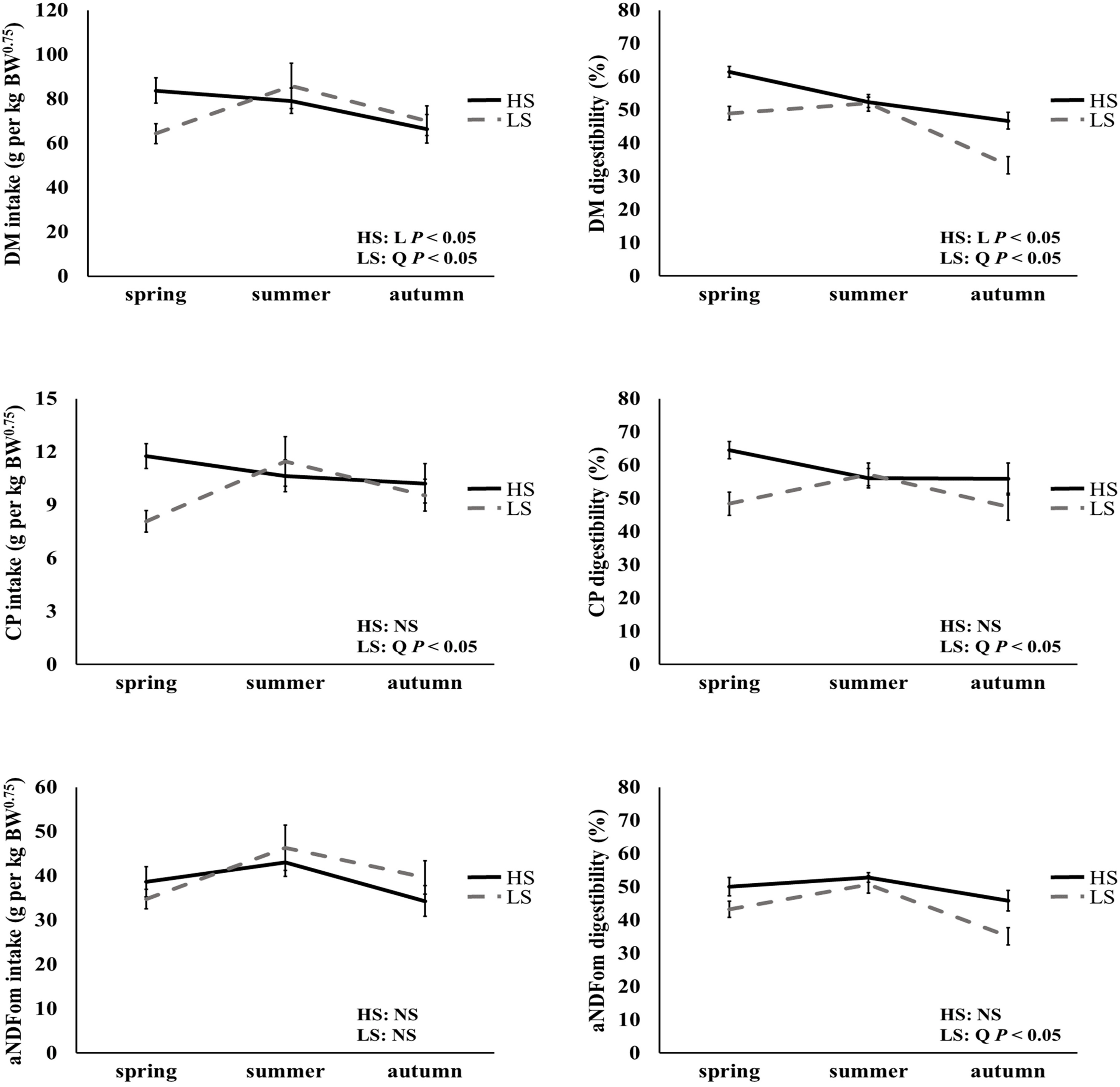
Figure 1 Seasonal changes in DM, CP and aNDFom intake and digestibility in grazing goats (means ± SE for five-year results). HS indicates 30–33 goats per ha, and LS indicates 14 goats per ha. In the statistical analysis, L, Q and NS indicate the results of an orthogonal contrast analysis. L represents a seasonally linear trend, Q represents a seasonally quadratic trend, and NS indicates no trend.

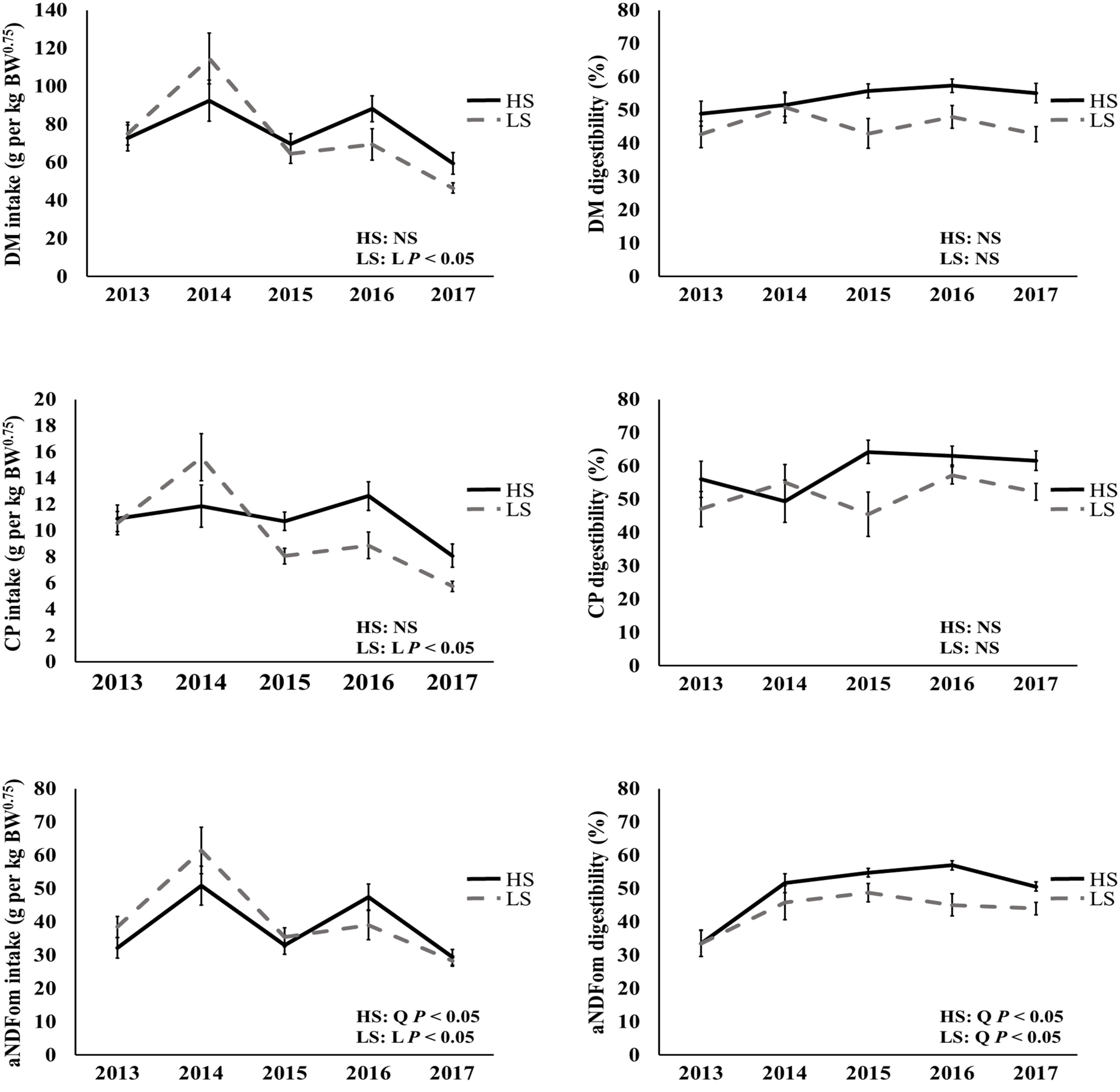
Figure 2 Changes in DM, CP and aNDFom intake and digestibility in grazing goats with year (means ± SE for five-year results). HS indicates 30–33 goats per ha, and LS indicates 14 goats per ha. In the statistical analysis, L, Q and NS indicate the result of an orthogonal contrast analysis. L represents a linear trend, Q represents a quadratic trend, and NS represents no trend in relation to the year.

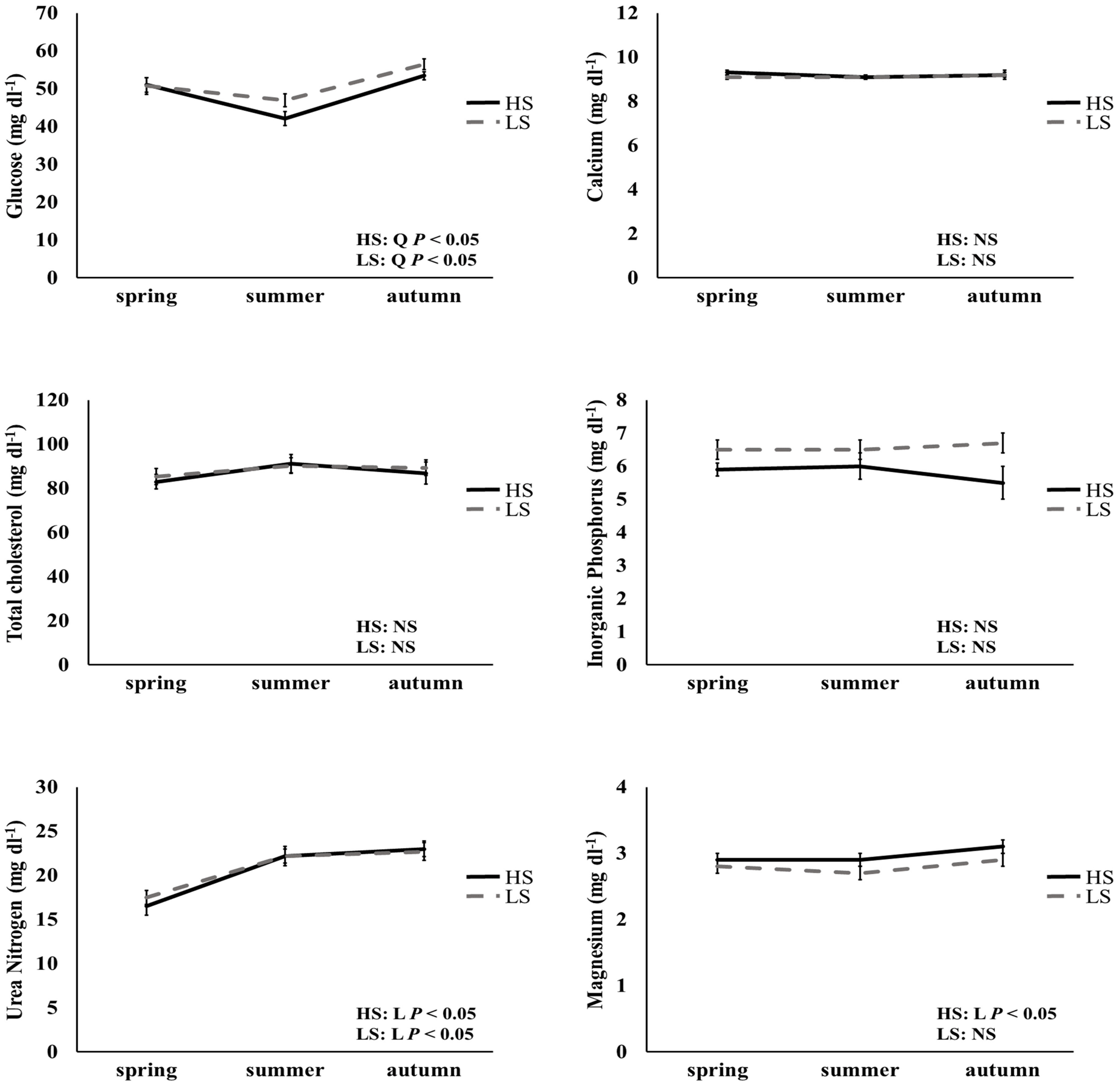
Figure 3 Seasonal changes in serum glucose, TCHO, UN, Ca, IP and Mg concentrations in grazing goats (means ± SE for five-year results). HS indicates 30–33 goats per ha, and LS indicates 14 goats per ha. In the statistical analysis, L, Q and

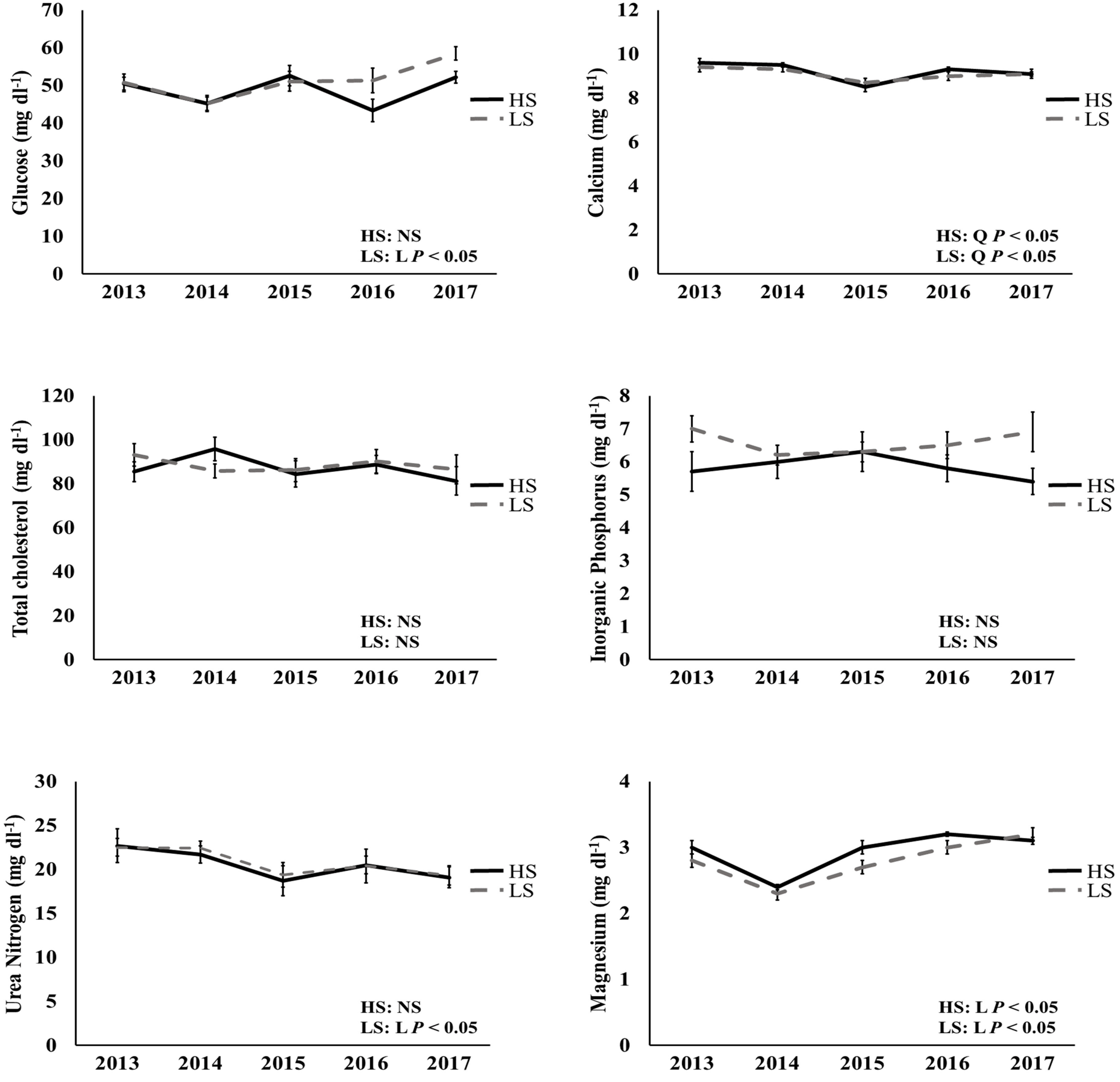
NS indicate the results of an orthogonal contrast analysis. L represents a seasonally linear trend, Q represents a seasonally quadratic trend, and NS indicates no trend.

Figure 4 Changes in serum glucose, TCHO, UN, Ca, IP and Mg concentrations in grazing goats according to year (means ± SE for five-year results). HS indicates 30–33 goats per ha, and LS indicates 14 goats per ha. In the statistical analysis, L, Q and NS indicate the results of an orthogonal contrast analysis. L represents a linear trend, Q represents a quadratic trend, and NS represents no trend according to year.


DM intake (g per kg BW0.75)
120
100
80
60
40
20
0
spring
summer
autumn
HS
LS
HS: L P < 0.05
LS: Q P < 0.05
DM digestibility (%)
80
70
60
50
40
30
20
10
0
spring
summer
autumn
HS
LS
HS: L P < 0.05
LS: Q P < 0.05
CP intake (g per kg BW0.75)
15
12
9
6
3
0
spring
summer
autumn
HS
LS
HS: NS
LS: Q P < 0.05
CP digestibility (%)
80
70
60
50
40
30
20
10
0
spring
summer
autumn
HS
LS
HS: NS
LS: Q P < 0.05
aNDFom intake (g per kg BW0.75)
60
50
40
30
20
10
0
spring
summer
autumn
HS
LS
HS: NS
LS: NS
aNDFom digestibility (%)
80
70
60
50
40
30
20
10
0
spring
summer
autumn
HS
LS
HS: NS
LS: Q P < 0.05


DM intake (g per kg BW0.75)
HS
LS
HS: NS
LS: L P < 0.05
DM digestibility (%)
HS: NS
LS: NS
CP intake (g per kg BW0.75)
HS: NS
LS: L P < 0.05
CP digestibility (%)
HS: NS
LS: NS
aNDFom intake (g per kg BW0.75)
HS: Q P < 0.05
LS: L P < 0.05
aNDFom digestibility (%)
HS: Q P < 0.05
LS: Q P < 0.05
2013
2014
2015
2016
2017


Glucose (mg dl-1)
70
60
50
40
30
20
10
0
spring
summer
autumn
HS
LS
HS: Q P < 0.05
LS: Q P < 0.05
Calcium (mg dl-1)
12
10
8
6
4
2
0
spring
summer
autumn
HS
LS
HS: NS
LS: NS
Total cholesterol (mg dl-1)
120
100
80
60
40
20
0
spring
summer
autumn
HS
LS
HS: NS
LS: NS
Inorganic Phosphorus (mg dl-1)
8
7
6
5
4
3
2
1
0
spring
summer
autumn
HS
LS
HS: NS
LS: NS
Urea Nitrogen (mg dl-1)
30
25
20
15
10
5
0
spring
summer
autumn
HS
LS
HS: L P < 0.05
LS: L P < 0.05
Magnesium (mg dl-1)
4
3
2
1
0
spring
summer
autumn
HS
LS
HS: L P < 0.05
LS: NS



Glucose (mg dl-1)
70
60
50
40
30
20
10
0
2013
2014
2015
2016
2017
HS
LS
HS: NS
LS: L P < 0.05
Calcium (mg dl-1)
12
10
8
6
4
2
0
2013
2014
2015
2016
2017
HS
LS
HS: Q P < 0.05
LS: Q P < 0.05
Total cholesterol (mg dl-1)
120
100
80
60
40
20
0
2013
2014
2015
2016
2017
HS
LS
HS: NS
LS: NS
Inorganic Phosphorus (mg dl-1)
8
7
6
5
4
3
2
1
0
2013
2014
2015
2016
2017
HS
LS
HS: NS
LS: NS
Urea Nitrogen (mg dl-1)
30
25
20
15
10
5
0
2013
2014
2015
2016
2017
HS
LS
HS: NS
LS: L P < 0.05
Magnesium (mg dl-1)
4
3
2
1
0
2013
2014
2015
2016
2017
HS
LS
HS: L P < 0.05
LS: L P < 0.05