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Effects of herbage mass and herbage quality on spatially heterogeneous grazing by cattle in a bahia grass (*Paspalum notatum*) pasture

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Abstract

Small-scale patches (locations of 50 cm × 50 cm at a feeding station level) in a bahia grass (*Paspalum notatum*) pasture under cattle grazing were investigated in terms of herbage mass, quality and utilisation during a grazing season (May–November), to characterise the quantity-quality relationship of patches and relate this to spatially heterogeneous grazing by animals. Nitrogen concentration and dry matter digestibility of herbage at the locations tended to be similar across herbage mass in May–June (late spring–early summer), but decreased with increasing herbage mass in July–November (mid-summer–late autumn). Cattle consumed more herbage from locations with higher herbage mass in May when the mean pre-grazing herbage mass (HM_{pre}) in the pasture was low (<1600 kg/ha DM), but not in October when the mean HM_{pre} was high (>2800 kg/ha DM). The results show that patches with higher herbage mass are advantageous to grazing animals in terms of both quantity and quality of herbage in late spring–early summer, whereas they are advantageous only in terms of quantity in the subsequent months. The study also shows that grazing animals modify their selectivity for patches according to the quantity–quality relationship of patches as well as the mean HM_{pre} in the pasture.

Introduction

In spatially heterogeneous vegetation, grazing by large herbivores is also spatially heterogeneous because they select preferred patches (Illius *et al.* 1987; Hirata and Fukuyama 1997; Cid and Brizuela 1998; Hirata 2000a, 2000b). The patch selection by animals is regarded as a 'trade-off' between quantity and quality of herbage (Stephens and Krebs 1986). For example, experiments with artificially prepared swards have demonstrated that animals selected patches with higher herbage mass (HM) because of the higher intake rate (Black and Kenny 1984; Illius and Gordon 1993; Illius *et al.* 1999). On the contrary, other reports have shown that animals preferred shorter patches with lower HM (McNaughton 1984; Illius *et al.* 1987) due to the higher digestibility and nitrogen concentration of herbage (Bakker *et al.* 1983; Illius *et al.* 1987; Cid and Brizuela 1998). However, with large herbivores in field experiments, the 'trade-off' concept has not been completely accepted because patch selection by animals grazing natural vegetation involves many factors which are interrelated. For instance, quantity and quality of herbage change simultaneously (Distel *et al.* 1995). Defaecation and trampling also affect patch selection by animals (Vallentine 2000).

Previous studies which quantified HM and consumption at a small-patch scale (50 cm × 50 cm) in a bahia grass (*Paspalum notatum*) pasture showed that herbage consumption by cattle was spatially heterogeneous and the manner of patch selection changed with season; *i.e.* the animals grazed more herbage from patches with higher pre-grazing HM as the mean pre-grazing HM in the pasture decreased (Hirata and Fukuyama 1997; Hirata 2000a, 2000b). However, due to a lack of patch quality data, these studies were not able to elucidate the mechanisms of such patch selection in terms of the trade-off between quantity and quality of herbage. A similar trend in patch selectivity was also observed on a daily basis with the progress of grazing in summer (Hirata and Ogura 2001a; 2001b); however, it is unclear whether this trend occurs in other seasons.

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Thus, we investigated small-scale patches in a bahia grass pasture grazed with cattle throughout a whole grazing season (spring–autumn), aiming to: 1) quantify the relationship between HM and herbage quality of patches across the grazing season; 2) monitor the dynamics in patch selectivity by animals on both seasonal and daily bases; and 3) associate the patch selectivity with the quantity and quality of herbage in patches.

Materials and methods

The site, pasture and animals

A 1.06 ha paddock of a Pensacola bahia grass pasture at the Sumiyoshi Livestock Farm (31°59′N, 131°28′E), Faculty of Agriculture, Miyazaki University, Japan was used for the study. The paddock was one of 5 paddocks (total area = 6.3 ha) rotationally grazed by Japanese Black cows and calves from May to October–November. The vegetation was dominated by bahia grass and virtually monospecific in summer and autumn (June–November).

In 1999, during the grazing season (about 187 days, May–November), the paddock was grazed by 30–33 cows and 9–13 calves (mean liveweight of cows = 457 kg) for six 4- to 6-day periods (May 22–25, June 21–25, August 3–7, September 13–18, October 22–25 and November 6–11; 09.00–16.00 h each day). Calves consumed negligible herbage in the pasture, because they were at a pre-weaning stage (<4 months old) and separately fed with concentrate and ryegrass hay. The annual fertilisation rates in the paddock were 70 kg N (split applications in April and August), 17 kg P (April), and 20 kg K (April) per ha. The paddock was mowed to a height of 9 cm above ground level on April 20, to remove spring weeds.

Meteorological data were recorded at Miyazaki Agricultural Experiment Station (2 km from the experimental site) and compared with the long-term (1971–2000) means.

Measurements

In the present study, HM, herbage quality and consumption were estimated at individual locations with an area of 50 cm × 50 cm. The area was selected based on the feeding station of cows. A feeding station is defined as the area of forage accessible by the neck and head of an animal while the front legs are stationary (Coleman *et al.* 1989).

Relationships between quantity and quality of herbage

The measurements were made on May 16, June 15, July 23, September 5, October 17 and November 20, 1999. Eight to 10 locations were selected in the paddock to cover a range of HM in the paddock at approximately constant intervals. Areas in the vicinity of a fixed line transect, used for the measurements of 'the spatial pattern of HM and rate of defoliation by cattle' (refer to the next section), were avoided. Herbage samples were cut at a height of 3 cm at the locations, and dried at 85°C for 48 h to determine HM (dry matter [DM], kg/ha). The dried samples were ground to pass a 1-mm screen, and nitrogen concentration (NC, g/kg DM) (AOAC 1984) and *in vitro* dry matter digestibility (DMD, g/kg DM) (Goto and Minson 1977) were determined as measures of herbage quality.

Spatial pattern of HM and rate of defoliation by cattle

The measurements were carried out during 3 grazing periods: May 22–25, August 3–7 and October 22–25, 1999. The spatial distributions of HM and the rate of defoliation were quantified every day during each period at ninety-one 50 cm × 50 cm locations spaced at 1-m intervals along a 90-m permanent line transect crossing the paddock (Transect 2 in Hirata and Fukuyama 1997; Hirata 1998, 2000a, 2000b; refer to Hirata [2000a] for the position of the transect). HM (above 3 cm height) at individual locations was non-destructively estimated immediately before grazing on Day 1 (HM_{pre} on Day 1), and after grazing on Days 1–4 (May and October) or Days 1–5 (August), using an electronic capacitance probe (PastureProbe™, Mosaic Systems Ltd, New Zealand). The corrected meter reading of the electronic capacitance probe was measured at 5 different positions in an area of 50 cm × 50 cm for each location, and the mean value was recorded as the corrected meter reading of the location. This reading was converted into HM (kg/ha DM) with a calibration equation which was developed on every measurement occasion. The HM_{pre} on Days 2–5 was assumed to be equal to the post-grazing HM on the previous day. The rate of defoliation at the individual locations was estimated every day, as the sum of the rate of decrease in HM (apparent consumption) and the rate of herbage accumulation under grazing which was estimated by equations proposed by Hirata (2000b). Spatial heterogeneity in HM and the rate of defoliation along the transect was expressed by CV.

Results

The meteorological conditions are shown in Figure 1. Mean air temperature was highest in late August (27.9°C) and lowest in late November (12.5°C). Maximum and minimum air temperatures were observed in late August (32.6°C) and late November (8.2°C). The mean air temperature during the grazing season was 22.2°C, which was the same as the long-term mean. Solar radiation was relatively high in early to mid-May and July–August and low in June and October–November. Rainfall was high in late July–early August, and low in October–November. Total amount of rainfall during the grazing season was 2128 mm, which was greater than the long-term mean (1763 mm).

Relationships between quantity and quality of herbage

The relationships between HM and herbage quality changed with season (Figure 2). In May–June (late spring–early summer), both NC

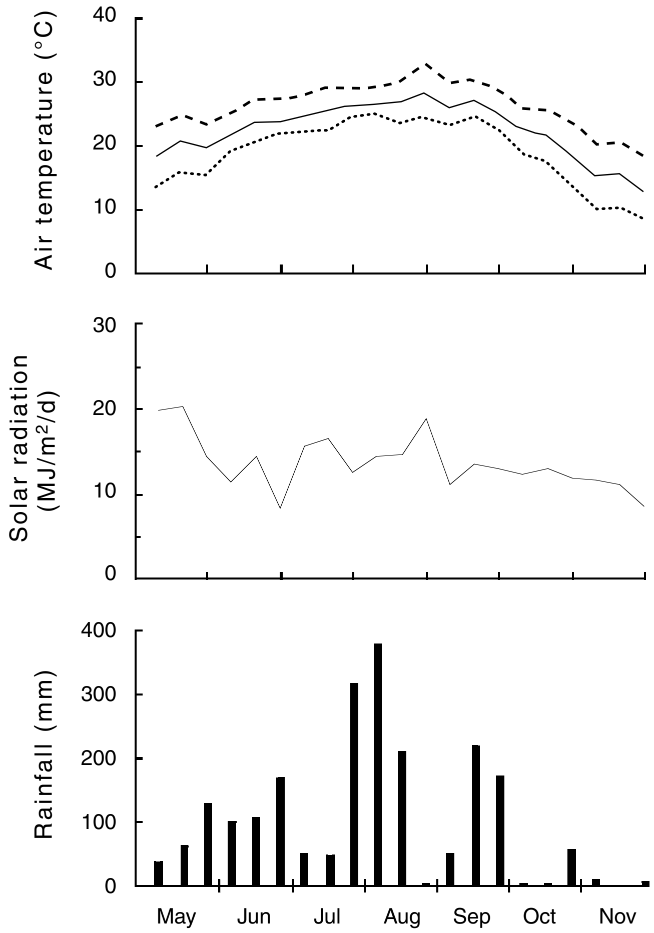

Figure 1. Ten- or 11-day average of maximum (- - - - -), mean (——) and minimum (-------) daily air temperatures, daily total shortwave solar radiation, and 10- or 11-day totals of rainfall during the study period.

and DMD showed high values of 20.9–28.7 g/kg DM and 492–612 g/kg DM, respectively, except for one sample. Although they tended to increase as HM increased ($P<0.05$), the correlation coefficient (r) was relatively low, indicating that NC and DMD differed little across HM. In July–October (mid-summer to mid-autumn), NC and DMD showed lower values (11.6–21.2 g/kg DM and 346–495 g/kg DM, respectively) than in May–June; with a further reduction (9.8–15.9 g/kg DM and 287–449 g/kg DM, respectively) in November (late autumn). In these 2 periods, both NC and DMD decreased as HM increased ($P<0.05$). There was a closer correlation (greater absolute value of r) between quality and HM in July–November than in May–June.

Spatial pattern of HM and rate of defoliation by cattle

The spatial distributions of HM_{pre} and the rate of defoliation along the line transect were quantified as shown by Figures 3 and 4, respectively. Mean HM_{pre} decreased with the progress of grazing in all months. In contrast, the CV of HM_{pre} increased with the progress of grazing. At some locations, the rate of defoliation showed negative values because of errors in the estimation (Hirata 2000b) (Figure 4).

The correlation between HM_{pre} and the rate of defoliation at individual locations along the line transect was related to the mean HM_{pre} of the pasture (Figure 5). The correlation was highest in May when the mean HM_{pre} was low (approximately <1600 kg/ha DM), indicating that cattle consumed more herbage from locations with greater HM_{pre}. By contrast, the correlation was lowest (negative or close to zero) on Days 1–3 in October when the mean HM_{pre} was high (approximately >2800 kg/ha DM), indicating that cattle consumed more herbage from locations with lower HM_{pre} or consumption was not related to HM_{pre} at individual locations. Similar trends were shown on daily data taken within each grazing period, except for May, when the correlation between HM_{pre} and the rate of defoliation was almost constant. The above trends in the correlations between HM_{pre} and the rate of defoliation can be seen by comparing the similarity or dissimilarity of the patterns in Figures 3 and 4.

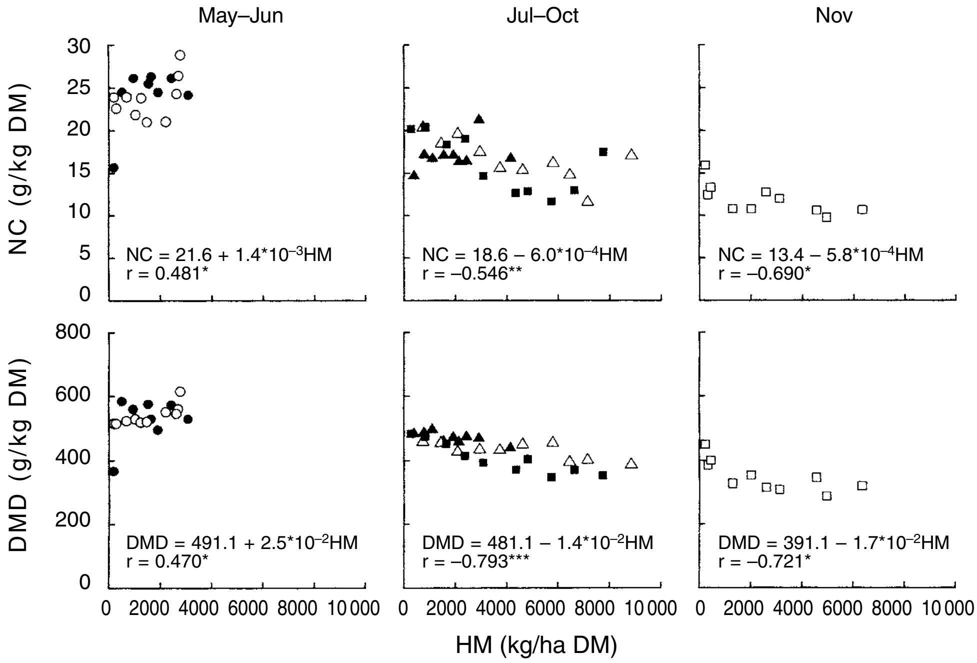

Figure 2. Relationships of nitrogen concentration (NC) and *in vitro* dry matter digestibility (DMD) to herbage mass (HM): May 16 (●), June 15 (○), July 23 (▲), September 5 (△), October 17 (■) and November 20 (□).

Discussion

The present study has provided valuable information on the relationships between HM and herbage quality in small-scale patches, and their effects on herbage consumption patterns by cattle.

It is widely accepted that short patches with low HM have high herbage quality and *vice versa*, because both nutritive value and digestibility decrease with an increase of HM and/or maturity (Burns *et al.* 1989). The present results, however, show that this is not always the case in a bahia grass pasture; *i.e.* patches with higher HM had a similar herbage quality to patches with lower HM during late spring–early summer (Figure 2). The probable explanation for this is that new high-quality green (live) leaves comprise the majority of bahia grass herbage in late spring–early summer (Higashiyama and Hirata 1995; Hirata 1996). Under these conditions,

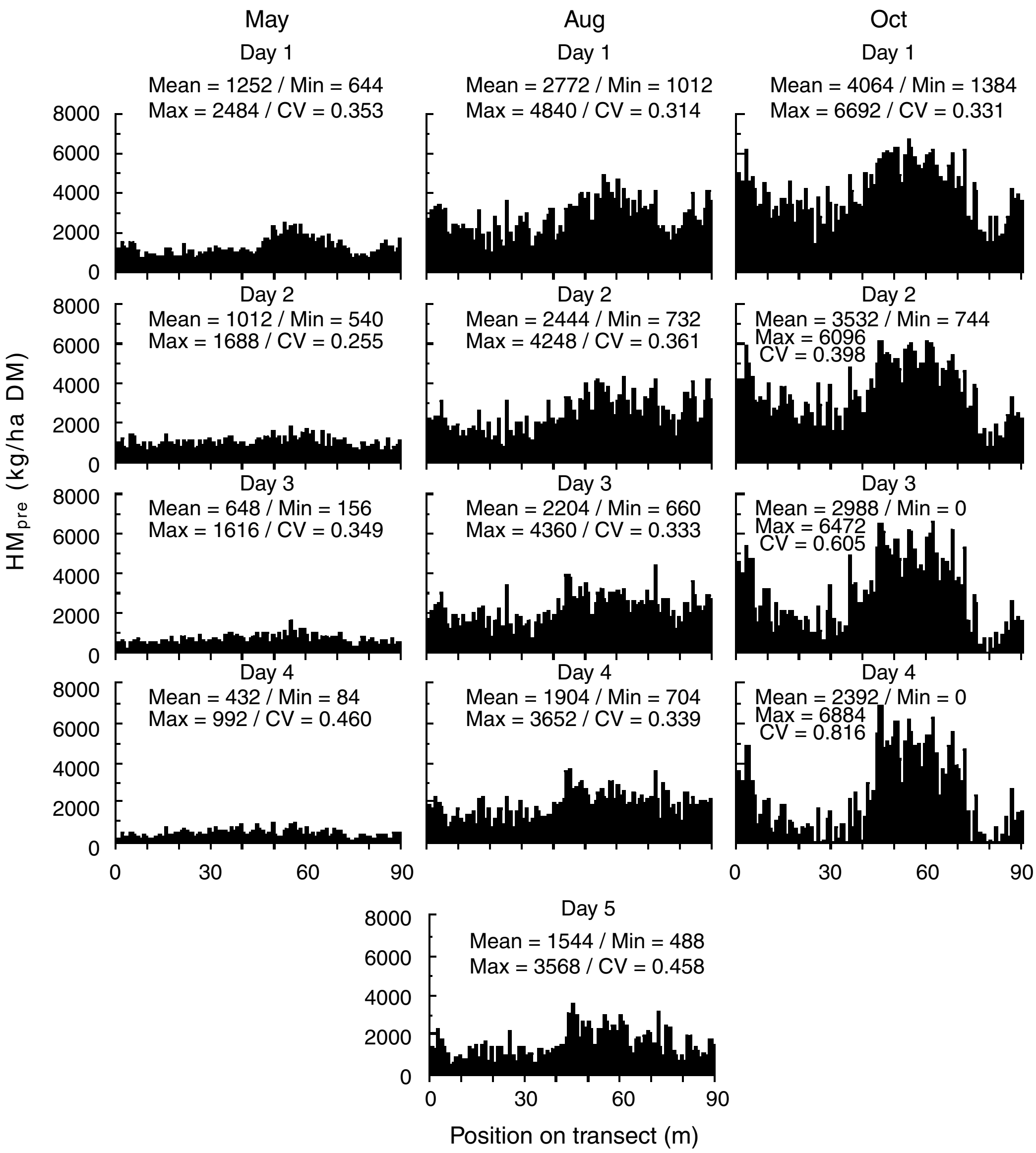

Figure 3. Distributions of pre-grazing herbage mass (HM_{pre}) along the line transect. The statistical parameters are mean, minimum, maximum and CV.

cattle consumed herbage in proportion to the HM of the patches. This indicates that there was no trade-off between quantity and quality at this time, and animals merely maximised rate of intake by selecting patches with high HM.

In contrast, during mid-summer to late autumn, herbage quality was lower in locations with higher HM (Figure 2). This may be due to the increasing composition of stem and/or dead materials (Higashiyama and Hirata 1995) of low quality in high HM patches. Higher quality in patches with lower HM may be due to the higher proportion of green leaves of regrowth. Under these conditions, the trade-off between quantity and quality of herbage could occur, and selection of patches might be determined by balancing the DM intake rate with the concentrations of nutrients. By late autumn, the pasture was of considerably lower quality (NC = 9.8–15.9 g/kg DM, DMD = 287–449 g/kg DM). During October, either

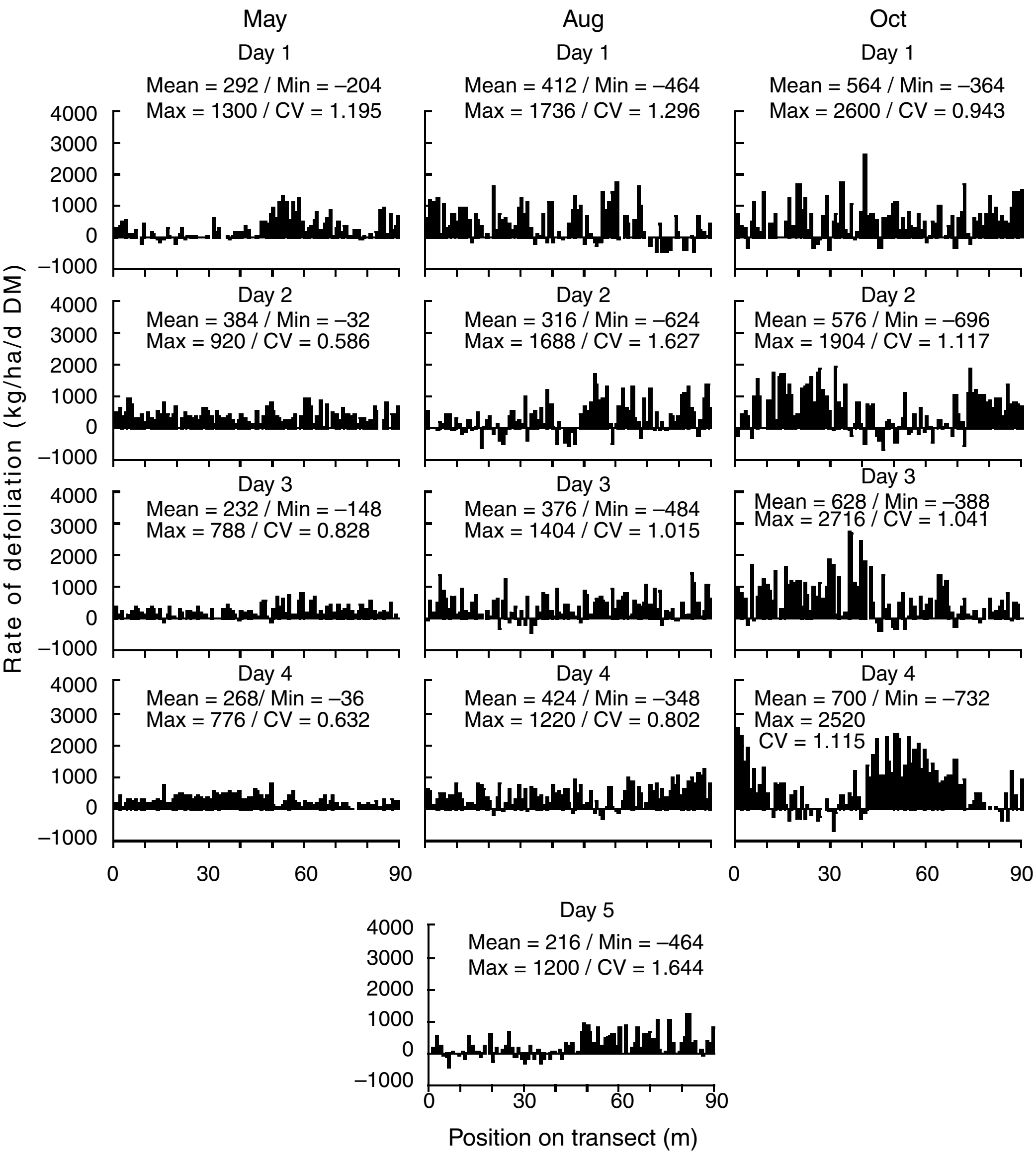

Figure 4. Distributions of the rate of defoliation along the line transect. The statistical parameters are mean, minimum, maximum and CV.

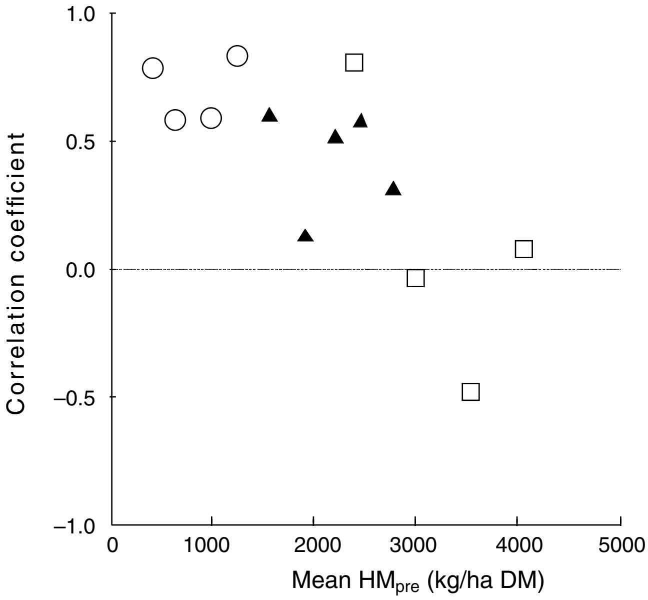

Figure 5. Effect of the mean pre-grazing herbage mass (mean HM_{pre}) over the line transect on the correlation coefficient between the rate of defoliation and the HM_{pre} along the transect: May (○), August (▲) and October (□).

grazing animals consumed more herbage from patches with lower HM or herbage consumption was independent of the HM on individual patches on Days 1–3. Then, on Day 4, they traded quality for quantity and switched to patches with higher HM, as the mean HM fell toward 2000 kg/ha DM. Thus, the change in patch selectivity by animals is attributed to the depletion of quality feed (*i.e.* green leaves) in patches with low HM. It has been reported that the quality of a pasture decreases with the duration of grazing due to increasing proportions of stem and dead material in the remaining pasture (Chacon and Stobbs 1976; Dougherty *et al.* 1990), which affects grazing behaviour of animals (Hendricksen and Minson 1980; Dougherty *et al.* 1990; Seman *et al.* 1999). The patch selectivity by animals during August grazing appears intermediate between that for May and October grazing, because pasture vegetation was intermediate in terms of both quantity (Figure 3) and quality (Figure 2).

The rates of defoliation estimated in the present study would include not only plant materials grazed by animals but also those detached by trampling. Vallentine (2000) reports that trampling by animals can reduce herbage availability through detachment of plant materials, particularly by enhancing the detachment of dead leaves. However, the present study dealt with herbage above 3 cm height, which usually contained few dead leaves (<10% green) as a substrate of detachment (Pakiding and Hirata 2001) through the grazing season. Although dead material above 3 cm height tended to increase as the grazing season progressed, it was mainly located in the tip to middle part of live leaves (≥10% green), which were not readily detachable by trampling by animals. Therefore, the rates of defoliation estimated in this study are considered to reflect herbage consumption by animals.

The present study showed the relation of the mean HM_{pre} in the pasture to the correlation coefficients between HM_{pre} and the rate of defoliation at individual locations, which were consistent with the previous findings on a seasonal basis (Hirata and Fukuyama 1997; Hirata 2000a, 2000b). The study also implied that there were similar trends in the changes in the correlations with the progress of grazing on a daily basis. Such seasonal and daily changes in the patch selectivity by animals reflected changes in both the quantity–quality relationship of patches and the mean HM_{pre} in the pasture. However, spatial variations in herbage consumption across patches were generally not highly accounted for either by quantity or quality of herbage in the patches, highlighting the importance of measuring or estimating quantity and quality of sward components (*e.g.* leaves, stems and dead material). Further research on spatially heterogeneous vegetation in terms of both quantity and quality, and the association of grazing behaviour by herbivores with the vegetation at a small-patch scale, will contribute to a deeper understanding of spatially heterogeneous grazing by animals in spatially heterogeneous vegetation and to the development of pasture and grazing management strategies considering spatial aspects of grassland resources.

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