SPATIAL DISTRIBUTION OF FAECES BY CATTLE IN A DAYTIME GRAZING SYSTEM

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Summary

Spatial distribution of faeces by Japanese Black heifers and steers was investigated. The animals grazed a bahiagrass (*Paspalum notatum* Flügge) pasture in the daytime from 9 a.m. to 4 p.m., and spent the rest of the day in a barn. The pasture consisted of three paddocks, an alley and a resting area, and the paddocks were grazed rotationally. The number of defecations and the faecal weight excreted in the pasture were greater than those expected from the proportion of time that the animals spent in the pasture. These values were correspondingly smaller in the barn. The distribution of faeces to the paddock, alley and resting area of the pasture was usually not proportional to the area of the respective places. The number of defecations and the faecal weight were usually distributed less densely in the paddock than in the resting area. The degree of aggregation of defecation in the paddock, alley and resting area varied with the meteorological factors such as the air temperature, solar radiation and rainfall during the grazing, and the intake of hay supplement on the previous day.

(**Key Words** : Beef Cattle, Daytime Grazing, Faeces, Spatial Distribution)

Introduction

In animal production systems, animal excreta, viz. faeces and urine, have various meanings. In some systems excretal products are important as a fertilizer or fuel, while in other systems they cause environmental pollution. Furthermore, in intensive grazing systems, faeces from animals are often responsible for increased patchiness of sward vegetation and reduced utilization of pastures (Marsh and Campling, 1970; Watkin and Clements, 1978; Wilkins and Garwood, 1986; Hirata et al., 1991). Thus, animal excreta are important outputs of concern in animal production systems, particularly in terms of sustainability of the system (Spedding, 1995).

A beef heifer/steer system utilizing a bahiagrass (*Paspalum notatum* Flügge) pasture in a low altitude region of southwestern Japan was selected as a case study for system management (Higashiyama and Hirata, 1995abc). In this system, animals graze the pasture in the daytime and spend the rest of the day in a barn, and are fed supplements when necessary. Most of the supplements are hay or silage produced from arable land components of the system, and the excreta produced in the barn are used as a fertilizer to the arable land. Information on the proportions of excreta distributed to the pasture and barn is necessary to estimate the amount of nutrients available as a fertilizer to the arable land.

During grazing in this system, animals can move freely within the pasture between a paddock, an alley and a resting area with shade trees and a watering place. It is therefore likely that the excreta are distributed unevenly within the pasture (Hakamata, 1980; Sugimoto et al., 1987ab; Hirata et al., 1990ab). Furthermore, changes in the supplementary feeding management and meteorological conditions may influence the evenness in the spatial distribution. This information is important to estimate the amount of nutrients returned to the sward vegetation in the pasture.

The present study was conducted to obtain the above information for the system management. Because of the

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ease in measuring the quantity, this study dealt with faeces, leaving urine to a future study.

Materials and Methods

The study was conducted between May and October in 1994 in a Japanese Black heifer/steer system at the Sumiyoshi Livestock Farm, Faculty of Agriculture, Miyazaki University (31° 59′ N, 131° 27′ E). Basically, the study was not experimental, accepting the management circumstances of the Farm. For instance, as described below, the study accepted the changes in the number and sex of animals, and the quality of supplements during the study (table 1).

In the system, 5 to 12 animals rotationally grazed three paddocks of a Pensacola bahiagrass (*Paspalum notatum* Flügge) pasture in the daytime between 9 a.m. and 4 p.m. (figure 1). The animals spent the rest of the

TABLE 1. OUTLINES OF MEASUREMENT PERIODS

Period no.	Date[a]	Paddock grazed[b]	Number of animals[c]	Mean live-weight (kg/hd)[d]	Intake of supplement (kg DM/hd)[e]	Herbage mass (g DM/m²)[f]	Mean air tempera-ture (℃)[g]	Solar radia-tion (MJ/m²)[h]	Rain-fall (mm)[h]	Measure-ment of faecal weight[i]
1	10-11 May	2	5	297	2.2	46	23.5	15.9	0.0	P
2	11-12 May	2	5	298	0.8	–	21.1	2.4	19.0	N
3	12-13 May	2	5	299	1.9	33	24.7	20.9	0.0	P
4	24-25 May	3	5	307	–	110	24.0	20.1	0.0	P
5	25-26 May	3	5	308	–	–	22.0	5.6	0.5	N
6	26-27 May	3	5	308	–	–	22.6	7.4	1.0	P
7	27-28 May	3	5	309	–	–	25.4	10.8	0.0	N
8	28-29 May	3	5	310	–	89	22.8	21.8	0.0	P
9	29-30 May	1	5	310	–	–	21.8	10.0	0.0	A
10	13-14 June	2	6	304	–	–	22.6	4.5	27.0	P
11	14-15 June	2	6	304	–	121	24.9	12.5	0.0	A
12	15-16 June	3	6	305	–	–	24.9	19.1	0.0	A
13	5- 6 July	2	6	313	1.5	–	31.8	21.5	0.0	A
14	6- 7 July	2	6	313	1.5	211	31.4	21.4	0.0	A
15	7- 8 July	3	6	313	1.5	–	30.4	21.0	0.0	A
16	12-13 Aug.	2	6	326	3.3	205	28.4	12.6	5.5	A
17	26-27 Aug.	3	12	289	2.7	326	30.9	15.1	0.0	A
18	27-28 Aug.	3	12	290	2.7	–	28.2	11.5	6.5	A
19	28-29 Aug.	3	12	290	2.6	–	30.0	17.5	0.0	A
20	14-15 Sep.	2	12	300	1.5	–	28.0	17.7	0.0	A
21	15-16 Sep.	2	12	300	1.6	310	27.2	17.4	0.0	A
22	16-17 Sep.	3	12	301	1.6	–	28.5	18.1	0.0	A
23	28-29 Sep.	3	12	309	1.5	206	23.3	1.1	5.5	A
24	11-12 Oct.	3	12	309	1.6	–	24.6	8.1	4.5	A
25	28-29 Oct.	2	12	312	3.1	–	24.1	14.1	0.0	A
26	29-30 Oct.	2	12	312	3.0	217	23.6	13.9	0.0	A
27	30-31 Oct.	3	12	313	3.1	–	22.4	14.0	0.0	A

[a] The duration of each period is 24 hours from 9 a.m. to 9 a.m.
[b] See figure 1.
[c] Heifers until Period 16, and 9 heifers and 3 steers thereafter.
[d] Calculated from half-monthly data (see text).
[e] Intake on the previous day of each period. - indicates no supplement feeding.
[f] Herbage mass above a 5 cm height. - indicates no measurement. For measurements, see text.
[g] Mean temperature over the daytime grazing from 9 a.m. to 4 p.m.
[h] Total value over the daytime grazing from 9 a.m. to 4 p.m.
[i] Measurements of faecal weight were not made (N), made for a part of defecations (P), or for as many defecations as possible (A).

day in a loose housing barn. The pasture, in addition to the three paddocks, included an alley and a resting area. The resting area had a watering place and shade trees. During the grazing, a gate leading to the barn was closed.

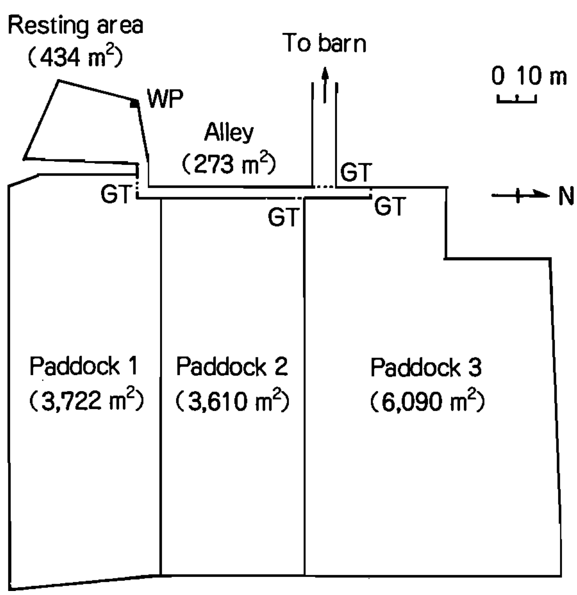

Figure 1. Physical characteristics of pasture.
GT and WP show a gate and a watering place, respectively. The resting area includes shade trees as well as WP.

The three paddocks were grazed orderly. Rotation to the next paddock was determined based on the herbage mass in the current paddock. The herbage mass was measured as described in Higashiyama and Hirata (1995a) or estimated by eye. The animals usually used Paddocks 1 and 2 for 3-5 days and Paddock 3 for 5-7 days, with shorter durations in spring and autumn than in summer.

The animals were supplemented except for late May to mid-June in the barn immediately after the grazing (table 1). The supplement was Italian ryegrass (*Lolium multiflorum* Lam.) hay in May to September, and guineagrass (*Panicum maximum* Jacq. var. maximum) hay in October. The quantity of supplements was varied experimentally (Higashiyama and Hirata, 1995c).

Measurements of the number of defecations and faecal weight were made in 27 periods of 24 hours (table 1). Except Period 9, periods when the animals grazed Paddock 2 or 3 were selected, bacause Paddock 1 was similar to Paddock 2 in size. In each period, by 4-5 observers, all the defecations by the animals were counted, and, during the grazing, the place of the defecation (paddock, alley or resting area) was recorded. Except for Periods 2, 5 and 7, the faecal weight was measured immediately after defecation occurred. When more-than-one dung pats were produced by a defecation, their total weight was measured. Thus, the faecal weight measured was the weight per defecation. The weighed faeces were returned to their original place of defecation so as not to modify pasture production and utilization and cattle behavior. When it rained intensively or the dung pats were trodden by the animals, the faecal weight was not measured. Contamination of faeces with urine rarely occurred even in the heifers, because defecation and urination did not occur simultaneously.

The animals were weighed half-monthly after an overnight fast. The liveweight in each investigation period (table 1) was estimated assuming linear liveweight changes between the measurements. The consumption of supplement was measured on the herd basis as the difference between the offered and residual amounts, and divided by the number of animals to give the intake. The meteorological factors were measured at the Farm.

The χ^2 test for goodness of fit was used to analyze the spatial distribution of defecations. The animals spent 7 hours in the pasture and 17 hours in the barn. Therefore, when the number of defecations in the two places is assumed to follow the proportion of time, the probability that defecation occurs in the pasture and barn is expected to be 0.292 and 0.708, respectively. The χ^2 goodness-of-fit test used this assumption as a null hypothesis, when the distribution to the pasture and barn was examined. The area of Paddocks 1, 2 and 3 was 3,722, 3,610 and 6,090 m^2, respectively, and the area of the alley and resting area was 273 and 434 m^2, respectively (figure 1). Therefore, when the number of defecations in the three places is assumed to follow the proportion of area, the probability that defecation occurs in the paddock, alley and resting area is respectively expected to be 0.840, 0.062 and 0.098 when Paddock 1 was grazed, 0.836, 0.063 and 0.101 when Paddock 2 was grazed, and 0.896, 0.040 and 0.064 when Paddock 3 was grazed. The χ^2 goodness-of-fit test used this assumption as a null hypothesis, when the distribution to the paddock, alley and resting area was examined.

Results

Distribution to pasture and barn

The number of defecations in the pasture and barn is shown in the left half of table 2. The number is expressed on the basis of the herd rather than on the basis of an animal so that the number can be used for the χ^2 test for goodness of fit. On average, 37.5% (range = 32.2

TABLE 2. NUMBER OF DEFECATIONS IN PASTURE AND BARN, AND IN PADDOCK, ALLEY AND RESTING AREA

Period no.	Number of defecations		P^b	Number of defecations			P^c
	Pasture[a]	Barn		Paddock[a]	Alley[a]	Resting area[a]	
1	27	35	< 0.05	18	3	6	< 0.1
2	27	33	< 0.01	15	11	1	< 0.001
3	30	33	< 0.01	12	0	18	< 0.001
4	26	39	< 0.1	22	1	3	< 0.75
5	26	37	< 0.05	19	2	5	< 0.05
6	28	37	< 0.05	28	0	0	< 0.25
7	23	37	< 0.25	18	0	5	< 0.01
8	34	42	< 0.01	26	0	8	< 0.001
9	27	38	< 0.05	23	1	3	< 0.9
10	27	55	< 0.5	17	8	2	< 0.001
11	26	40	< 0.1	20	3	3	< 0.75
12	26	49	< 0.5	22	1	3	< 0.75
13	45	58	< 0.01	25	3	17	< 0.001
14	42	55	< 0.01	27	6	9	< 0.01
15	35	59	< 0.1	29	0	6	< 0.05
16	36	62	< 0.1	26	4	6	< 0.25
17	64	126	< 0.25	35	4	25	< 0.001
18	68	122	< 0.05	37	6	25	< 0.001
19	74	128	< 0.05	42	5	27	< 0.001
20	69	136	< 0.25	44	7	18	< 0.001
21	74	114	< 0.01	56	4	14	< 0.05
22	80	120	< 0.001	45	3	32	< 0.001
23	58	122	< 0.5	38	20	0	< 0.001
24	59	119	< 0.25	48	6	5	< 0.05
25	72	129	< 0.05	64	6	2	< 0.25
26	68	119	< 0.05	54	10	4	< 0.05
27	65	116	< 0.05	56	2	7	< 0.5
Total	1,236	2,060	< 0.001	866	116	254	< 0.001
Mean	45.8	76.3	–	32.1	4.3	9.4	–

[a] Pasture = Paddock + Alley + Resting area (see figure 1).

[b] Probability that the number of defecations in the pasture and barn follows the proportion of the time that the cattle spent in the respective places, examined by the χ^2 test (see text).

[c] Probability that the number of defecations in the paddock, alley and resting area follows the proportion of the area of the respective places, examined by the χ^2 test (see text).

−47.6%) of defecations occurred in the pasture, and 62.5 % (range = 52.4−67.8%) in the barn. Thus, the percentage occurring in the pasture was always greater than that expected from the proportion of time (29.2%). The χ^2 goodness-of-fit test indicated that the null hypothesis was not accepted at 5% level in 16 periods and in the total periods. The percentage distribution to the pasture was not significantly correlated with the intake of supplement or any of the three meteorological factors shown in table 1.

Table 3 shows the faecal weight (fresh weight) excreted in the pasture and barn. To lessen the errors of estimation, the mean faecal weight per defecation was calculated using data from the periods when faecal weight in each place was measured for more than 80% of the defecations (compare the sample number in table 3 with the number of defecations in table 2). In each period, the mean weight per defecation ranged between 812 and 1,231 g in the pasture, and between 998 and 1,333 g in the barn. For the total periods, the mean weight was 967 and 1,143 g in the pasture and barn, respectively. The faecal weight per defecation showed a considerable variation in both the pasture and barn, but the mean weight was larger in the barn than in the pasture except for one period (Period 24).

The total faecal weight excreted in the pasture and barn (table 3) was calculated by multiplying the mean weight per defecation (table 3) by the number of defecations (table 2) for each place. On average, 32.8% (range = 28.8−38.3%) of faeces were excreted in the pasture, and 67.2% (range = 61.7−71.2%) in the barn. Thus, the percentage distribution to the pasture was always higher than that expected from the proportion of time (29.2%) except for one period (Period 12).

TABLE 3. FAECAL WEIGHT EXCRETED IN PASTURE AND BARN

Period no.	Mean weight per defecation (g)		Total weight excreted (kg)	
	Pasture[a]	Barn	Pasture[a]	Barn
9	966 (27)[b]	1,105 (37)[b]	26.1	42.0
12	955 (26)	1,248 (48)	24.8	61.2
13	812 (45)	1,142 (58)	36.5	66.2
15	843 (32)	1,162 (55)	29.5	68.6
16	884 (30)	1,041 (57)	31.8	64.5
18	873 (59)	1,059 (118)	59.4	129.2
19	828 (66)	1,086 (122)	61.3	139.0
20	920 (63)	998 (133)	63.5	135.7
21	851 (67)	1,098 (103)	63.0	125.2
22	834 (77)	1,127 (118)	66.7	135.2
23	1,169 (47)	1,233 (121)	67.8	150.4
24	1,231 (48)	1,178 (117)	72.6	140.2
25	1,072 (70)	1,171 (125)	77.2	151.1
26	1,132 (59)	1,170 (119)	77.0	139.2
27	1,126 (62)	1,333 (116)	73.2	154.6
Mean	967 (778)	1,143 (1,447)	55.4	113.5
SD[c]	375 (778)	615 (1,447)	–	–

[a] Pasture = Paddock + Alley + Resting area (see figure 1).
[b] Figures in the parentheses show the sample number.
[c] Standard deviation for all periods.

Distribution to paddock, alley and resting area

The number of defecations in the paddock, alley and resting area is shown in the right half of table 2. On average, 70.1% (range = 40.0−100.0%) of defecations occurred in the paddock, 9.4% (range = 0.0−40.7%) in the alley, and 20.6% (range = 0.0−60.0%) in the resting area. Thus, the percentage occurring in the paddock was usually smaller than the expected from the proportion of area (83.6-89.6%). By contrast, the percentage occurring in the resting area was usually larger than that expected from the proportion of area (6.4-10.1%). The χ^2 goodness-of-fit test showed that the null hypothesis was not accepted at 5% level in 18 periods and in the total periods.

Table 4 shows the faecal weight (fresh weight) excreted in the paddock, alley and resting area. Similarly to table 3, the mean faecal weight per defecation was calculated using data from the periods when faecal weight in each place was measured for more than 80% of the defecations (compare the sample number in table 4 with the number of defecations in table 2). In each period, the mean weight per defecation ranged between 731 and 1,194 g in the paddock, between 590 and 1,240 g in the alley, and between 742 and 1,373 g in the resting area. For the total periods, the mean weight was 923, 976 and 910 g in the paddock, alley and resting area, respectively. The faecal weight per defecation showed a considerable variation in all the three places. However, for the total periods, there were only small differences between the mean weights in the paddock, alley and resting area.

The total faecal weight excreted in the paddock, alley and resting area (table 4) was calculated by multiplying the mean weight per defecation (table 4) by the number of defecations (table 2) for each place. On average, 68.3%

(range = 50.3−90.2%) of faeces were excreted in the paddock, 10.0% (range = 0.0−33.1%) in the alley, and 21.7% (range = 0.0−44.9%) in the resting area. Thus, the percentage distribution to the paddock was usually lower than that expected from the proportion of area (83.6-89.6%). On the contrary, the percentage distribution to the resting area was usually higher than that expected from the proportion of area (6.4-10.1%).

TABLE 4. FAECAL WEIGHT EXCRETED IN PADDOCK, ALLEY AND RESTING AREA

Period no.	Mean weight per defecation (g)			Total weight excreted (kg)		
	Paddock[a]	Alley[a]	Resting area[a]	Paddock[a]	Alley[a]	Resting area[a]
8	754 (26)[b]	− (0)[b]	817 (7)[b]	19.6	0.0	6.5
9	920 (23)	790 (1)	1,373 (3)	21.2	0.8	4.1
12	970 (22)	740 (1)	910 (3)	21.3	0.7	2.7
13	809 (25)	1,240 (3)	742 (17)	20.2	3.7	12.6
19	731 (36)	590 (5)	1,015 (25)	30.7	3.0	27.4
22	796 (43)	870 (3)	883 (31)	35.8	2.6	28.3
23	1,194 (31)	1,121 (16)	− (0)	45.4	22.4	0.0
25	1,086 (63)	890 (5)	1,105 (2)	69.5	5.3	2.2
Mean	923 (269)	976 (34)	910 (88)	33.0	4.8	10.5
SD[c]	344 (269)	426 (34)	400 (88)	−	−	−

[a] See figure 1.
[b] Figures in the parentheses show the sample number.
[c] Standard deviation for all periods.

In order to quantify the degree of aggregation of defecation in the paddock, alley and resting area, the ratio of the observed number of defecations to the expected number was calculated. The expected number was calculated on the previously-described assumption that the number of defecations follows the proportion of the area of the three places. As illustrated in figure 2, the ratio in the paddock (Z_p) was usually less than 1. The ratio in the alley (Z_A) had distinct peaks with values of 4.7-8.6 in Periods 2, 10 and 23. The ratio in the resting area (Z_R) was usually higher than 1, and had as high values as 5.7-6.3 in Periods 3, 17-19 and 22. There were negative correlations between Z_p and Z_R ($r = -0.718$, $p < 0.001$), and between Z_A and Z_R ($r = -0.385$, $p < 0.05$).

Analyses of the relationships of Z_p, Z_A and Z_R to the intake of supplement and the meteorological factors (table 1) indicated a negative correlation between Z_p and the mean air temperature during the grazing (T) ($r = -0.409$, $p < 0.05$). Z_A was correlated negatively with the solar radiation (Q) ($r = -0.681$, $p < 0.001$) and positively with the rainfall (U) ($r = 0.645$, $p < 0.001$) during the grazing. Z_R was positively correlated with T ($r = 0.566$, $p < 0.01$) and Q ($r = 0.487$, $p < 0.01$).

Furthermore, multiple regression analyses (forward selection method, F_{IN} level = 0.05, variance inflation factor < 10), which used the intake of supplement and the three meteorological factors, and their non-linear transformations (square root, logarithmic and inverse) as potential predictors, resulted in the following equations:

$$Z_p = 1.487 - 0.025T - 0.00945U \quad (r = 0.546,\ p < 0.05) \quad (1)$$

$$Z_A = 0.784 + 16.07/(Q+1) + 0.084U - 1.327/(S+1) \quad (r = 0.942,\ p < 0.001) \quad (2)$$

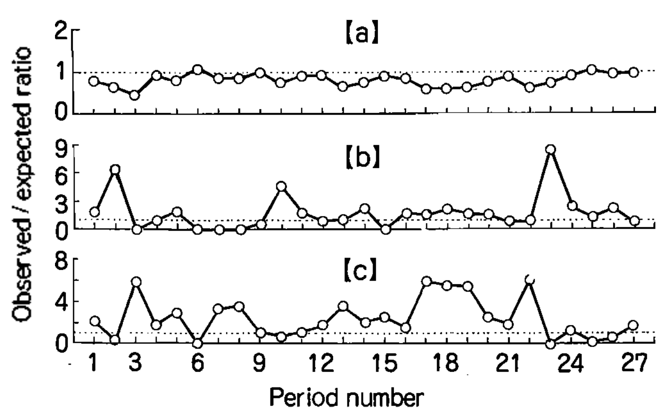

Figure 2. The ratio of observed number of defecations to expected number of defecations in the paddock [a], alley [b] and resting area [c]. Expected number of defecations was calculated assuming that the number of defecations follows the proportion of the area of the three places (see text).

$$Z_R = 12.12 - 252.8/(T+1)$$
$$(r = 0.572, p < 0.01) \cdots\cdots (3)$$

where S is the intake of supplement on the previous day.

Discussion

Distribution to pasture and barn

The distribution of faeces to the pasture and barn in the present study (tables 2 and 3) is the distribution in terms of time as well as space. The fact that the number of defecations in the pasture was higher than that expected from the proportion of time (table 2) means that the animals defecated more frequently per unit time in the pasture than in the barn. This result agrees with previous studies which report more frequent defecation by grazing cattle during the day than at night (Arnold and Dudzinski, 1978; Suzuki et al., 1983; Sugimoto et al., 1987a). On the other hand, the faecal weight per defecation tended to be smaller in the pasture than in the barn (table 3). Nevertheless, the faecal weight excreted in the pasture was still higher than that expected from the proportion of time except for one period (table 3). Thus, the present study indicates that the distribution of faeces to the pasture and barn, on the basis of both the number of defecations and the faecal weight excreted, can not be estimated simply as the proportion of time that the animals spent in the respective places. However, further analyses are necessary for developing an equation which explains the variation in the percentage distribution to the pasture and barn.

Distribution to paddock, alley and resting area

As anticipated from previous studies (Hakamata, 1980; Sugimoto et al., 1987ab; Hirata et al., 1990ab), the distribution of faeces within the pasture, i.e. the distribution to the paddock, alley and resting area, was usually biased from the proportion of the area of the respective places. Both the number of defecations (table 2) and the faecal weight excreted (table 4) were usually distributed less densely in the paddock than in the resting area. The ground of the alley and resting area was almost bare owing to treading by the animals. Therefore, the less dense distribution of faeces to the paddock may have considerable effects on the nutrient cycling in the system, because the nutrients in the faeces deposited in the alley and resting area are not recovered by the sward vegetation and hence by the animals. Sugimoto et al. (1987b) have pointed out the possible influences of uneven distribution of faeces and urine on nitrogen recycling in a bahiagrass pasture ecosystem.

The degree of aggregation of defecation in the paddock, alley and resting area varied with the investigation periods (figure 2). Z_P showed a negative correlation with T, and Z_R showed positive correlations with T and Q. These results accord with a widely-observed phenomenon that cattle on a pasture stop grazing and rest under shade trees in conditions of high air temperature and high solar radiation (Kurosaki et al., 1982; Suzuki et al., 1984; Sakurai and Dohi, 1988). However, the equations derived from the multiple regression analyses (equations 1 and 3) did not give sufficiently high correlation coefficient ($r = 0.546$ and 0.572), and this indicates a need for further analyses to improve the equations.

By contrast, the multiple regression equation for Z_A (equation 2) which incorporates Q, U and S as predictors gave a high correlation coefficient ($r = 0.942$). Q had a negative effect, and U and S positive effects on Z_A. In fact, when it rained intensively in the afternoon, it was observed that the animals gathered and kept standing in front of the gate leading to the barn for a few hours (refer to figure 1). In addition, it was observed that the grazing time of the animals in the paddock decreased as S increased (Higashiyama and Hirata, 1995b). The positive effect of S on Z_A reflects such behavior of the animals and the tendency of the animals to rely on the supplement supplied in the barn.

Implications to system management

Animal excreta are important outputs of concern in animal production systems (Spedding, 1995). The information obtained in the present study is useful for making the management strategy of the system. The percentage distribution of faecal weight excreted in the barn (table 3) is essential for estimating the amount of nutrients available as a fertilizer to the arable land of the system, though further analyses are necessary for developing a predictive equation. An example of the use of this information is a simulation approach which examined the effects of some management options on agricultural and ecological aspects of a dairy heifer system (Hirata et al., 1996).

The degree of aggregation of defecation in the paddock, alley and resting area (figure 2 and equations 1-3) is important in estimating the amount of nutrients returned to the sward vegetation in the pasture, though further analyses are needed for improving the prediction equations for the paddock (equation 1) and resting area (equation 3). Examples of the use of this kind of information are simulation approaches which evaluated the effects of faeces from grazing animals on pasture production (Hakamata, 1986; Hirata et al., 1991), and pasture utilization and animal production (Hirata et al., 1991).

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