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Effects of paracoprid dung beetles (Coleoptera: Scarabaeidae) on the growth of pasture herbage and on the underlying soil

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Abstract

Field and greenhouse experiments were conducted to determine effects of three paracoprid dung beetles, *Copris ochus* (Motschulsky), *Copris tripartitus* Waterhouse and *Onthophagus lenzii* Harold, on the growth of pasture herbage and physical characteristics of the underlying soil. Treatments consisted of beetles plus dung, dung only and controls with neither dung nor beetles present. In the field in 2001, higher herbage yields were obtained with *O. lenzii* ≥ *C. ochus* = *C. tripartitus* ≥ only dung = control after 5 months. The air permeability of soil at a depth of 10 cm was highest when *C. ochus* was present (0.56 cm h^{-1}), and lowest in the control (0.38 cm h^{-1}). However, no significant differences were found among treatments in air permeability at 20 cm. In 2002/2003, the presence of all three species of dung beetle together was associated with higher herbage yields and with higher percentage nitrogen content than the control. In the laboratory, the presence of *C. ochus* and *C. tripartitus* was found to increase significantly the total crude protein in grass shoots and total digestible nutrient, compared with the control. The digestibility, dry intake and relative feed value of perennial ryegrass were highest where feces had been buried by *O. lenzii*. Acid detergent fiber was low in all treatments. The data suggest that the tunneling of paracoprid beetles improves the physico-chemical characteristics of soil and increases the feed value of herbage by mixing and incorporating organic matter into the soil.

Keywords: Dung beetles; Herbage yield; Soil aeration; Feed value

1. Introduction

Dung beetles belong to the family Scarabaeidae, one of the largest families of beetles with approximately 30,000 species worldwide (Hanski and Cambefort, 1991). In Korea, there are about 90 species of dung beetle, belonging to five subfamilies and 11 genera (Kim, 1994). However, changes in livestock and pasture management during the past three decades are thought to have resulted in a general decline in dung beetle abundance and a reduction in the diversity of dung beetle communities, especially

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in mainland areas of Korea (Bang et al., 2001). Also, the widespread use of insecticides, herbicides, fungicides and veterinary parasiticides, many of which are excreted in the feces of treated livestock, may also have played a role in the decline of these beetle populations. In Korea, there have been few studies of the biology and ecology of dung beetles and this lack of data hinders the development of sustainable pasture management systems (Bang et al., 2000). It may, for example, be advantageous to carry out beetle mass-rearing and redistribution programs, similar to those undertaken successfully in Australia (Waterhouse, 1974) and the United States (Fincher, 1990).

Dung beetles are important agents for dispersing animal feces and incorporating them into the soil, thus enhancing nutrient cycling and the productivity of grassland ecosystems (Bornemissza, 1960; Fincher, 1981, 1990; Halffter and Edmonds, 1982; Hanski and Cambefort, 1991). Gillard (1967) stated that 80% of the nitrogen from feces remaining on the pasture surface is lost by volatilization but when sufficient numbers of dung beetles are present for quick burial, the loss is reduced to 5–15%. The rapid recycling of volatile nutrients in feces by the burying activity of dung beetles has also been shown to increase pasture yields as a result of the incorporation of organic matter into the soil, with a concomitant increase in soil friability, aeration, and water-holding capacity (Gillard, 1967; Bornemissza and Williams, 1970; Macqueen and Beirne, 1975). The rapid incorporation of organic matter into the soil has been shown to result in a reduction in livestock pests that breed in dung (Doube, 1986). There are also claims that the burrowing activity of dung beetles results in other benefits such as improved soil structure, increased aeration and better water penetration (Bornemissza, 1960; Waterhouse, 1974). However, these latter claims have been little studied and poorly documented.

This study was conducted to determine the effects of dung beetle activity on pasture productivity and soil structure using three paracoprid species which bury dung balls directly beneath the dung pat, *Copris ochus* Motschulsky, *Copris tripartitus* Waterhouse and *Onthophagus lenzii* Harold. These species were formerly widespread in the Korean peninsula (Paik, 1976). They are active from spring to autumn and are capable of burying large amounts of dung per day (Paik, 1976; Kim, 1994).

2. Materials and methods

2.1. Effects of dung beetles on herbage growth in the field

Adults of dung beetles were collected from fields on Jeju island (33°24′N, 126°28′E; elevation 700 m asl) and identified to species prior to use. Dung for use in the work reported here was obtained from cattle maintained on pastures at a dairy farm in Seo San (37°30′N, 127°00′E; elevation 250 m asl), 150 km south-west from Suwon, Korea. All field experiments were carried out in the experimental farm of the Sericultural and Entomology Department, National Institute of Agricultural Science and Technology (NIAST), Suwon, Korea. The main pasture plants at this site were orchard grass (*Dactylis glomerata* L.), tall fescue (*Festuca arundinacea* Schreb.), perennial ryegrass (*Lolium perenne* L.), alfalfa (*Medicago sativa* L.), and Kentucky blue grass (*Poa pratensis* L.). This complex of pasture plants is common in the central region of the Korean peninsula and is recommended by the National Livestock Research Institute, Korea. Commercial fertilizer (granule type; Namhae Chemical Co.; N–P–K = 8 g m^{-2}:7.4 g m^{-2}:6.8 g m^{-2}) was applied in early spring before beginning the field experiment. Plants were sown in March 2001.

For the field experiments, all plots (1 m^2) were completely enclosed by a roofed-cage of 0.2 mm gauze net. The outer edge of the net was buried 20 cm below the soil surface. Males and females of three species of dung beetles were then placed in “beetle” plots in late May. A standardized, 1 kg cattle dung pat was added to each “dung” plot, twice a month during the growing season and was always placed in the same location. Positive and negative controls, with no added beetles, contained either 1 kg per plot of fresh dung or no added dung, respectively.

In 2001, five treatments were established, consisting of the positive and negative controls plus plots containing either two pairs of *C. ochus*, three pairs of *C. tripartitus* or five pairs of *O. lenzii* beetles. The number of each dung beetle species added to each plot was based on their body size. The experimental design was a randomized complete block design with five treatments and three replications. The herbage in each plot was harvested on July 6, August 27 and November 8, and the dry weight was measured after drying at 80 °C in an oven for 2 days. Vegetation in the area surrounding the plots was also cut to a height of 5 cm at the same time. The air permeability of the soil was measured beneath the dung pat in each plot at 10 cm and 20 cm of a depth on November 12, 2001 using an air permeameter (DIK-5001, Daiki, RKW). By this stage of the season, dung beetles have normally finished feeding. Measurement was conducted in three positions per plot, using the method of Corey (1986). We found that dung beetles were still alive down to 70 cm deep in beetle plots even after the 2001 experiment, indicating that dung beetles were still active in the same locations as in the previous year when food was provided.

In 2002 and 2003, conditions were as described for the previous year, however, in these experiments, two pairs of *C. ochus*, three pairs of *C. tripartitus* and five pairs of *O. lenzii* beetles were added together to each beetle plot. Controls with no beetles and with or without added dung were also present, as described previously. There were 10 randomized replicates of the three treatments. Herbage in each experimental plot was harvested twice in 2002 and five times in 2003. Dry matter yields were compared between the three treatments as described previously. In addition, to consider seasonal changes in the nitrogen content of the herbage, the herbage was sampled once a month or twice a month and dried in a freezing dry chamber. The forage samples were ground into a fine powder in a mortar and the nitrogen content was determined by an element analyzer (Leco CHN 1000, USA).

2.2. Greenhouse experiments

Experiments were conducted in a greenhouse (20 ± 5 °C) of the NIAST in September 2001. Pots (41 cm × 33 cm × 23 cm) were filled with soil to a depth of 15 cm and then 500 g of fresh cattle dung and beetles were placed into the pots. Pots were covered with mesh net (0.2 mm) to prevent beetles escaping. Pots contained either one pair of *C. ochus*, two pairs of *C. tripartitus*, three pairs of *O. lenzii* or dung only. There were three replicates of the four treatments.

Beetles were allowed to feed for 40 days and then removed before sowing grass. Pots were sown with perennial ryegrass (*Lolium perenne* L.), at the rate of 2 g of seeds per pot and irrigated equally twice a week during the growing period. Shoots and roots of grass were harvested 70 days after sowing. Roots were thoroughly washed three times with distilled water to remove soil particles. Both shoots and roots were dried at 80 °C for 2 days and ground for NIR chemical analysis (NIR systems Inc., 1990, ISI program). Crude protein (CP), total digestible nutrient (TDN), acid detergent fiber (ADF), and dry matter digestibility (DMD) were determined at mowing (Burns and Lacefield, 1991). Relative feed value (RFV) was calculated by the equation of Holland and Kezar (1990). The crude protein content of the herbage was calculated as percent total N × 6.25.

2.3. Data analysis

All the data were tested for normality and homogeneity, and then were subjected to ANOVA for treatment effects on the yield of herbage, nitrogen content and soil air permeability and feed value of herbage using the SYSTAT program (version 9.0, SPSS Inc.). The data from the field experiments were first analysed by two-way ANOVA with dung beetle treatment and harvesting date as factors. However, since no significant dung beetle × harvesting date interactions were detected, data for individual sampling dates and total herbage yield were analysed separately by one-way ANOVA. Estimates of yield of forage were based on dry weights of each treatment.

3. Results

3.1. Effects of dung beetles on herbage growth in the field

In 2001, 40 days after dung beetle release, the dry matter yield of herbage did not differ among treatments (Table 1). However, after 3 months (August 2001), the dry matter yield of herbage was higher in all the dung beetle plots than in the control plots. The plot containing *C. ochus* produced a slightly higher yield than others at that time. The highest total annual yield was produced in the plot containing *O. lenzii*, with an

Table 1
Mean dry matter (g m^{-2} ± S.D.) of herbage harvested from three 1 m^2 field plots per treatment in pastures at the experimental farm of the Sericultural and Entomology Department, National Institute of Agricultural Science and Technology (NIAST), Suwon, Korea in 2001

Treatment	July 2001	August 2001	November 2001	Total
Control	250.00 ± 19.08^{a}	170.67 ± 45.18^{b}	76.00 ± 28.00^{b}	496.67 ± 49.66^{b}
Only dung	262.33 ± 28.43^{a}	204.87 ± 32.76^{b}	62.00 ± 8.72^{b}	529.20 ± 52.89^{b}
C. ochus	246.33 ± 48.09^{a}	282.00 ± 43.86^{a}	$75.33 \pm 11.71^{a,b}$	$603.66 \pm 52.52^{a,b}$
C. tripartitus	244.67 ± 19.63^{a}	261.33 ± 75.51^{a}	$75.33 \pm 11.71^{a,b}$	$581.33 \pm 68.00^{a,b}$
O. lenzii	242.00 ± 46.52^{a}	270.66 ± 50.29^{a}	100.67 ± 1.15^{a}	613.33 ± 88.23^{a}

Plots contained no beetles or dung, dung only or dung plus beetles of the species shown. Means within columns with the same superscript (a and b) are not significantly different using ANOVA. L.S.D. (5%).

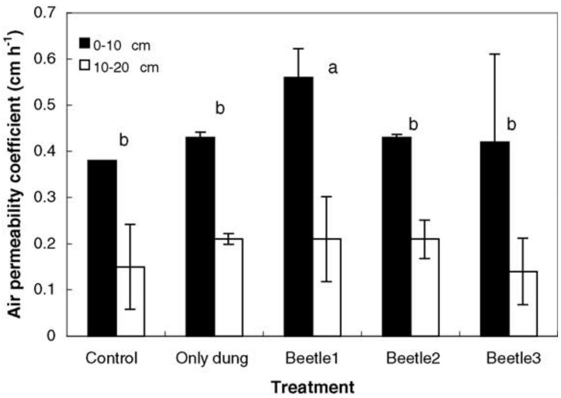

Fig. 1. Comparison of air permeability coefficients of soil cores following 172 days of dung burial activity by paracoprid dung beetles. 'Beetle 1' is *C. ochus*, 'Beetle 2' is *C. tripartitus* and 'Beetle 3' is *O. lenzii*. Means with the same letter are not significantly different using ANOVA. L.S.D. (5%).

average 613.3 g of dry matter. Where the feces were buried by the dung beetles, the yearly total dry matter yield tended to be higher than the control. The soil air permeability was significantly different among treatments at 10 cm depth but not at 20 cm. At 10 cm, air permeability was significantly higher in the plot containing *C. ochus* (Fig. 1).

For the experiments carried out in 2002/2003, the results of yield and nitrogen content analyses are shown in Table 2 and Fig. 2. The yield of herbage in September 2002 and July 2003 were highest where feces had been buried by the beetles. In July 2002, an infestation of the Oriental armyworm, *Mythimna separata* Walker destroyed vegetation unequally in the experimental field site, and therefore, we could not obtain herbage yield data from July to August. The nitrogen content of herbage with dung beetle

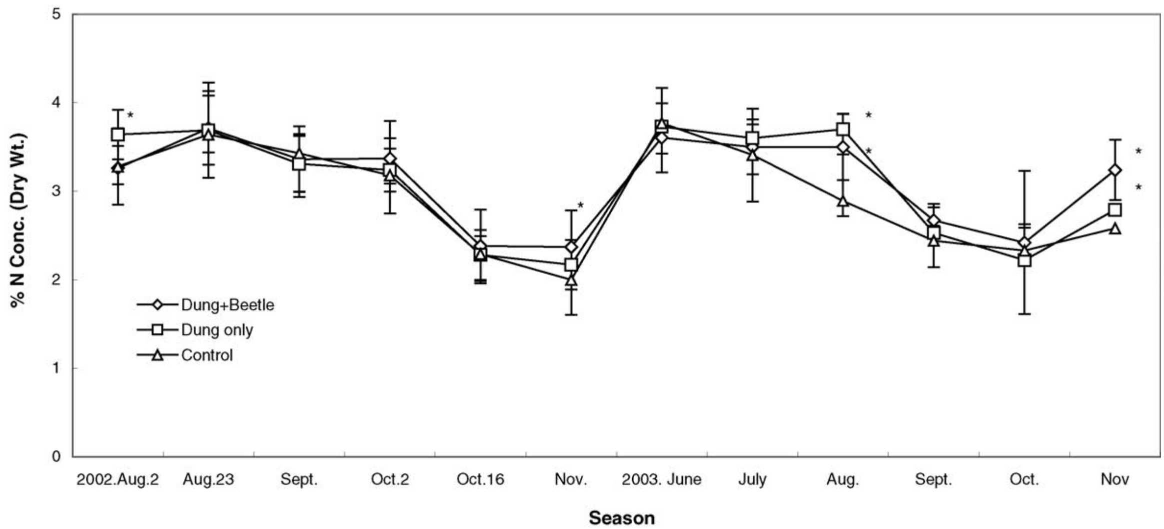

Fig. 2. Effect of dung beetle on nitrogen content of forage (±S.D.). 'Dung + beetle' is the treatment with *C. ochus*, *C. tripartitus* and *O. lenzii*. 'Control' is without dung and dung beetles. Treatments marked with an (*) denote a significant difference from the control treatment. L.S.D. (5%).

Table 2
The yield (g m^{-2} ± S.D.) of herbage in each treatment in 2002 and 2003

Treatment	2002			2003					
	September	October	Total	June	July	August	October	November	Total
Dung + beetle	222.87 ± 13.73^{a}	121.11 ± 23.87	343.98 ± 30.17^{a}	126.62 ± 24.76	258.25 ± 21.38^{a}	155.55 ± 27.40	197.69 ± 34.25	137.13 ± 25.85	875.24 ± 86.79^{a}
Dung only	196.89 ± 10.37^{b}	114.11 ± 19.80	311.00 ± 33.91^{b}	121.23 ± 15.02	240.46 ± 12.27^{b}	144.38 ± 23.21	193.21 ± 33.81	128.80 ± 28.75	$828.08 \pm 15.80^{a,b}$
Control	$208.94 \pm 10.31^{a,b}$	112.09 ± 22.01	$321.03 \pm 39.95^{a,b}$	105.57 ± 21.64	216.49 ± 9.31^{c}	157.55 ± 24.02	178.92 ± 34.54	126.46 ± 28.71	784.99 ± 60.49^{b}

'Dung + beetle': with *C. ochus*, *C. tripartitus* and *O. lenzii*. 'Control': without dung and dung beetles. Means within columns with the same superscript (a–c) are not significantly different using ANOVA. L.S.D. (5%).

treatment was also higher than with dung treatment and control (Fig. 2).

3.2. Greenhouse experiements

Substantial differences in yield were obtained for different beetle species (Table 3). The total crude protein in shoots increased with *C. ochus* or *C. tripartitus* treatments, while it did not with *O. lenzii*. Total digestible nutrients (TDN) increased in all dung beetle treatments compared to the control. Nutrient feed value was highest in the *O. lenzii* treatment (Table 3). The TDN content of grass was highest in the *O. lenzii* treatment and lowest in the control. The dry matter digestibility (DMD) and relative feed value (RFV) of grass were significantly higher in *O. lenzii* treatment than others ($P < 0.05$). The two other beetle species did not significantly improve these values. Acid detergent fiber (ADF) in beetle treatments was lower than that in the control, although statistically significant differences were not found. Therefore, the activity of dung beetle did not have harmful effects on grass properties such as causing nitrogen surplus and altering the nutrient feed value.

4. Discussion

Dung is rich in nitrogen and also contains considerable amounts of phosphorus and calcium, but it is low in potassium (Huttonm et al., 1967). The most efficient use of fecal nitrogen is made by plants after fresh dung has been buried in the soil. In the field experiment carried out in 2001, the plot containing *C. ochus* produced a significantly higher yield in August. This shows that *C. ochus* can disperse cow dung rapidly in the summer season, whereas *C. tripartitus* stay in the chambers that they excavate in the soil to care for their brood balls from late spring to summer (Bang et al., 2001). It seems that air permeability was higher in plots containing *C. ochus* than in any other plots, which is related to the body size of *C. ochus*. The transmission of gas and liquid through the soil is related to the size and continuity of soil pore spaces. The results indicate that the activity of the beetles affected the air permeability at 10 cm depth, but deeper soil was not affected. However, the methods used here could examine only the vertical activity of

Table 3
Effects of dung beetle activity on yield and feed value of Perennial ryegrass in a greenhouse experiment

Treatment	Yield tops + roots (g)	Total crude protein in tops (g)	TDN (%)	ADF (%)	DMD (%)	RFV (%)
C. ochus	32.3 ± 5.24^{a}	9.4 ± 0.49^{a}	79.4 ± 1.07^{b}	12.0 ± 1.35^{a}	4.06 ± 0.29^{b}	231.7 ± 21.7^{b}
C. tripartitus	26.1 ± 1.42^{b}	8.9 ± 0.60^{a}	79.1 ± 0.37^{b}	12.6 ± 0.47^{a}	4.11 ± 0.16^{b}	232.5 ± 10.79^{b}
O. lenzii	$30.0 \pm 0.40^{a,b}$	7.1 ± 0.32^{b}	79.6 ± 0.53^{a}	11.8 ± 0.67^{a}	4.81 ± 0.36^{a}	275.6 ± 20.69^{a}
Control	25.3 ± 1.69^{b}	6.9 ± 0.74^{b}	78.2 ± 0.28^{c}	13.1 ± 0.19^{a}	4.34 ± 0.18^{b}	228.4 ± 17.40^{b}

TDN: total digestible nutrient ± S.D., ADF: acid detergent fiber ± S.D., DMD: Dry matter digestibility ± S.D., RFV: relative feed value ± S.D. Means within columns with the same superscript (a–c) are not significantly different using ANOVA. L.S.D. (5%).

the beetles in the soil. Further study is needed, using other methods, to examine the activity of beetles in the deeper soil because of the non-linear shape of the tunnels they create. Also, the plots with dung, but without beetles, produced higher dry matter yields than the plots with neither dung nor beetles. This result may be due to the activity of other coprophagous fauna, particularly the earthworms that naturally occurred in the field experiment since they are responsible for a significant proportion of the consumption and removal of dung (Holter, 1977). However, under northwestern European conditions, earthworms generally appear at the pats 2 weeks after pats are deposited on the surface while dung beetles appear in the pat and surrounding soil immediately (Holter, 1979). Among the coprophagous arthropods, dung beetles burrow within the cow dung pats and they can accelerate the return of nitrogen and other nutrients from dung to the soil (Stevenson and Dindal, 1987). Their activity also affects microbial populations in cow dung, usually accelerating bacterial growth (Breymeyer et al., 1975) and altering environmental conditions, with increased ammonification, nitrification and denitrification, as well as N_2-fixation (Yokoyama et al., 1991).

In the field experiments carried out in 2002/2003, the burial of the feces by dung beetles appeared to increase both dry matter yields and the nitrogen content of herbage. McKinney and Morley (1975) summarized the Australian research on dung beetles on nutrient cycling and reported that about 200 kg N/ha were normally cycling in a highly productive pasture on an annual basis. They stated that 60% of the total N was returned to the pasture as urine, 20% as dung, and 20% as decaying herbage. They concluded that dung burial might reduce fecal N losses and enhance N utilization for a certain period, but that the area affected was likely to be less than 15% of the total, and the increased production was slightly higher than on pastures to which N fertilizer was regularly applied. Macqueen and Beirne (1975) found that burial of an average 37% of the available dung by beetles caused a 38% increase in crude protein over that of the control, while crude protein production of grass treated with 67 kg N/ha was 95% higher than the control. The results of Yokoyama et al. (1991) indicated that dung beetles affected denitrification in a manner somewhat similar to that noted for earthworm casts, in that the supplies of available energy and NO_3–N and the consumption of O_2 by active microorganisms enhanced the potential for denitrification (Svensson et al., 1986).

In conclusion, the data reported here indicate that herbage feed-value was increased by dung burial and the consequent fertilizing effect of beetle activity. Three paracoprid species, *C. ochus* Motschulsky, *C. tripartitus* Waterhouse and *O. lenzii* Harold, represent the dung beetle community in Korea. But the activity of Coprini species, *C. ochus* and *C. tripartitus*, have declined in pasture farms of mainland Korea mainly due to decline in their populations. In practice, to maintain maximum dung burial from spring to autumn in Korean pastures, it would be desirable to have a succession of dung beetle species with complementary periods of seasonal activity which are able to live together with minimal competition, as a result of their different ecological requirements, feeding, and nitrification habits. Therefore, it should be important to develop a program to conserve and enhance the three paracoprid species complex in Korean pasture.

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