Diversity of coprophagus invertebrates in Korea and their role in soil ecosystem-mainly dung beetles

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Abstract

Dung beetles and earthworms act as removes dung on the ground from the soil surface. Dung beetles bury the dung in the soil wherever they find it. This helps to accelerate the rate of the circulation of nutrients and to increase the productivity of grassland ecosystem. They use dung as their food and as their offspring. As the result of these activities there were noticeable changes in the soil. Different species of dung beetle in Korea were found in different soil layers. Chemical properties and microbial interactions by three paracoprid dung beetles (*C. ochus, C. tripartitus* and *O. lenzii*), were studied during dung decomposition periods. Each three dung beetles contributed the changes in the chemical composition and microbiological activity of each soil layer as the result of using by their different ecological niche.

In the earthworms and dung beetles interaction experiment, dung decomposition rate was higher in the pots treated with both earthworms and dung beetles than in the pots with either earthworms or beetles alone. Dung beetles were responsible for dung decomposition until 78% moisture content in the dung, earthworms were responsible for up to 30% moisture of dung, and two groups were not shown any activity for decomposition less 30% moisture content of dung. Therefore dung in the different periods could be broken down by each group. For maximum benefits of the effective earthworms and dung beetles, it is needed to preserve population of earthworm and dung beetles for sustainable agricultural environment.

Key words: dung beetle, earthworm, decomposition, soil

Introduction

Dung beetles (Scarabaeidae) are one of the largest families of beetles with approximately 30,000 species worldwide (Hanski and Cambefort, 1991). In Korea, there are about 65 species of dung beetle, belonging to five subfamilies and ten genera (Paik, 1976). Kim (1994) found that 13 species, including *Gymnopleurus mopsus* (Pallas) and *Scarabaeus typhoon* (Fischer-Waldheim), has disappeared from cattle producing area among 90 dung beetles species. During the past decades the changes in livestock and pasture management have resulted in the reduction of the diversity of dung beetle (Bang et al., 2001). The widespread use of insecticides, herbicides, fungicides and veterinary parasiticides, many of which are excreted in the feces of treated livestock, may have caused the decline of these beetle populations. The conservation of extincted species and revitalization of the population for dung beetle in the agroecosystem should be needed.

In Korea, there is a little information on the effect of dung beetle in soil and pasture ecosystem. Moreover, the interactions involved between dung beetles, earthworm, soil, plants. This study is mainly concerned with three major dung beetles which are important biological agents of dung dispersal in the pastoral areas of Korea and to determine the effects of dung beetle activity on pasture productivity and soil structure using three paracoprid species *C. ochus, C. tripartitus* and *O. lenzii* which bury dung balls directly beneath the dung pat. This study will provide basic data on role of Korean dung beetles and earthworms on agro-environment.

1. Dung beetles in Korea

The research of Korean dung beetles was started with description of rolling dung beetle, *Gymnopleurus mopsus* by Kolbe (1886). After that, surveys of the dung beetles fauna at 131 different localities during the 1960s identified 65 species of dung beetles belonging to 10 genera and 5 sub-families by Paik (1976). Aphodiinae accounted for more than half of the species recorded, but two ball rolling species, *Gymnopleurus mopsus* and *Scarabaeus affinis*, and two paracoprids, *C. ochus* and *Onthophagus lenzii*, were regarded as being the main species responsible for dung dispersal (Paik, 1976). Each of the latter species was recorded as being widespread, and all were active between late spring and early autumn. However, more recent observations suggest that in the years since Paik's survey, both *G. mopsus* and *S. affinis* have disappeared completely from all cattle producing areas of Korea (Kim, 1994). In addition, there has been a substantial decline in the abundance of *C. ochus*, at least on the mainland. The species is of importance in the Korean peninsula and Jeju Island because they can use lots of dung for their offspring and food in pasture land. 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 in mainland areas of Korea (Kim, 1984; Bang et al., 2001). Livestock and pasture management practices seem likely to have been important contributors to this decline and hence the changes that have occurred in these activities over the past 20-30 years need to be investigated (Wardhaugh Pers. Communication).

According to their nesting behavior, dung beetle divided into three groups. The ball rollers or telecoprids carve chunks of dung out of the pad, knead them into balls and roll them away for burial. The endocoprids build their nests inside dung pads. The most common dung beetles are the paracoprids, which bury dung beneath or around dung pad.

Telecoprid

Originally, three telecoprid beetles, *Gymnopleurus mopsus*, *Scarabaeus affinis* Brulle and *Sisyphus schaefferi* was commonly distributed in Korea. Among the three rolling beetles, *G. mopsus, S. affinis* also were regarded as being the main species responsible for dung dispersal (Paik, 1976). Although *G. mopsus*, and *S. affinis* were recorded as being widespread in Korea from spring to autumn. The more, recent observations suggest that in the years since Paik's survey, both *G. mopsus* and *S. affinis* have disappeared completely from all cattle producing areas of Korea (Fig. 1).

Endocoprids

There is three or four endocoprid beetle species commonly found in the cow dung throughout Korea. These include the three aphodiines, *Aphodius propraetor* Bulthasar, *Aphodius rectus*

Motschulsky and *Aphodius elegans* Allibert, the adults of which are 4-6 mm long. No brood balls are produced by these species, the larvae feeding from the dung surrounding them. It happens two times a year, spring and autumn, they were showed the highest activity in pasture. Most of endocoprid is small species in Korea but, they appeared often and amount of each species is high so endocoprid is also important role of dung dispersal in Korea (Fig. 1).

Paracoprids

Coprini : Copris species plays an important role in the reduction of dung breeding flies. As this kind of reason, many country introduced Copris species to control flies. The two species coprini dung beetles (*C. ochus* and *C. tripartitus*) distributed all of the Korean peninsula (Paik, 1976)(Fig. 1). However, they were found Gangwon-do and Jeju-do which is distributed main pasture farm in Korea for last three years. Activity of Coprini is in close synchrony with seasonal climatic conditions. For example, Bang et al. (2001) reported coprini active in July and August when 60% over rain. Paik (1976) found that *C. ochus* could survive under Korean winter conditions as adults having observed tunneling activity up to next spring.

Oniticellini : There is only one species in Korea (Kim, 1994). *Liatongus phanaeoides* (Westwood) is distributed in throughout the country. It was collected in number at an elevation from 600 to 800 m pasture farm from Spring to Autumn. Peak activity of *L. phanaeoides* occurred from August through October (Fig. 1).

Onthophagini : The 27 species native onthophagus dung beetles have been established in this country. Among the onthophagini, *Onthophagus japonicus* Harold, *Onthophagus fodiens* Harold, and *Onthophagus lenzii* Harold is occupied over 60% of dung beetle in Korea (Kim, 1994). *Onthophagus lenzii* Harold is the most common one and is widely distributed throughout the country. Above ground activity is most commonly seen during spring and autumn. This species was investigated in all sampling site in this study (Fig. 1).

	
Telecoprid in Korea. *Scarabaeus typhoon* (Fischer-Waldheim)	Endocoprid in Korea. *Aphodius elegans* Allibert

	
Paracoprid-coprini in Korea. *Copis ochus* (Motschulsky) male	Paracoprid- oniticellini in Korea. *Liatongus phanaeoides* (Westwood)
	
Paracoprid- onthophagini in Korea. *Onthophagus lenzii* Harold	Paracoprid- onthophagini in Korea. *Onthophagus japonicus* Harold

Fig. 1. Dung beetles in Korea

2. Role of dung beetles

The beneficial effects of cattle dung to grassland ecosystems have been well documented (Bornemissza, 1960). Gillard (1967) stated that 80% of the nitrogen content of dung is denatured by bacteria and lost by volatilisation when sheep and cattle dung remains on the pasture surface. When adequate dung beetle numbers are present and bury the faeces the nitrogen loss is markedly reduced, to approximately 10%. Several studies have shown that grass growth is benefited when the nutrients present in faeces are quickly recycled within the pasture ecosystem once buried by dung beetles (Bornemissza, 1960; Holter, 1977, 1979). In addition to adding nutrients to the soil, dung beetles aid in prevention of pasture fouling. Cattle dung remaining on the soil surface can kill plants, slow regrowth under the dung pat, and render neighboring plants unpalatable as forage. Pasture fouling can ultimately affect 4.2–12 times the area covered by dung, potentially covering up to 85 % of total pasture area, and persist for up to 18 months. The rapid burial of dung prevents or minimizes these effects of dung deposition. Dung beetles act as useful biological control agents reducing fly pests and the free living stages of gastro-intestinal parasites of live stock. In doing so, beetles out-compete fly larvae and may cause physical damage to fly eggs and larvae while feeding on and preparing dung for brood balls. Dung beetle contribute to physical breakdown of organic matter thus their activity also affects microbial populations in cow dung, usually accelerating bacterial growth.

2.1. Effects of paracoprid dung beetles on the growth of pasture herbage and on the underlying soil

2.1.1 Effects of dung beetles on herbage growth

Where the feces were buried by the dung beetles, the yearly total dry matter yield was significantly higher (*P<0.05*) than the control. At 10cm, air permeability was significantly higher in the plot containing *C. ochus* (Fig. 2). The yield of herbage in September, 2002 and July, 2003 were highest where feces had been buried by the beetles. The yield in dung beetle treatments tended to be higher than in feces treatment and control. The nitrogen content of herbage with dung beetle treatment was also higher than with dung treatment and control (Fig. 3).

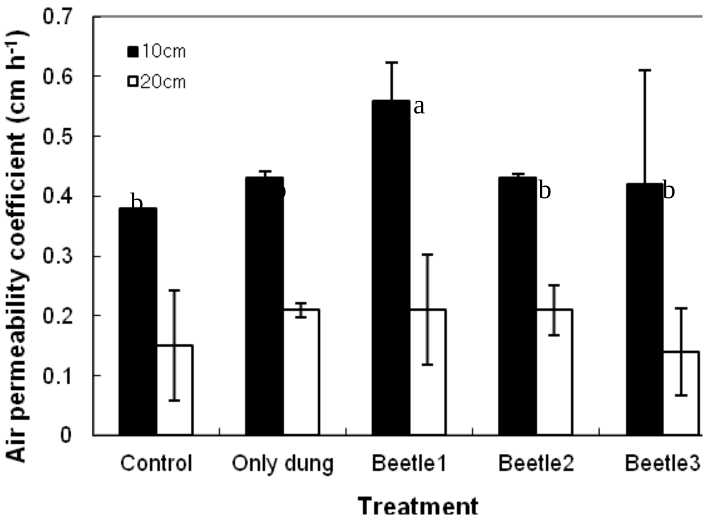
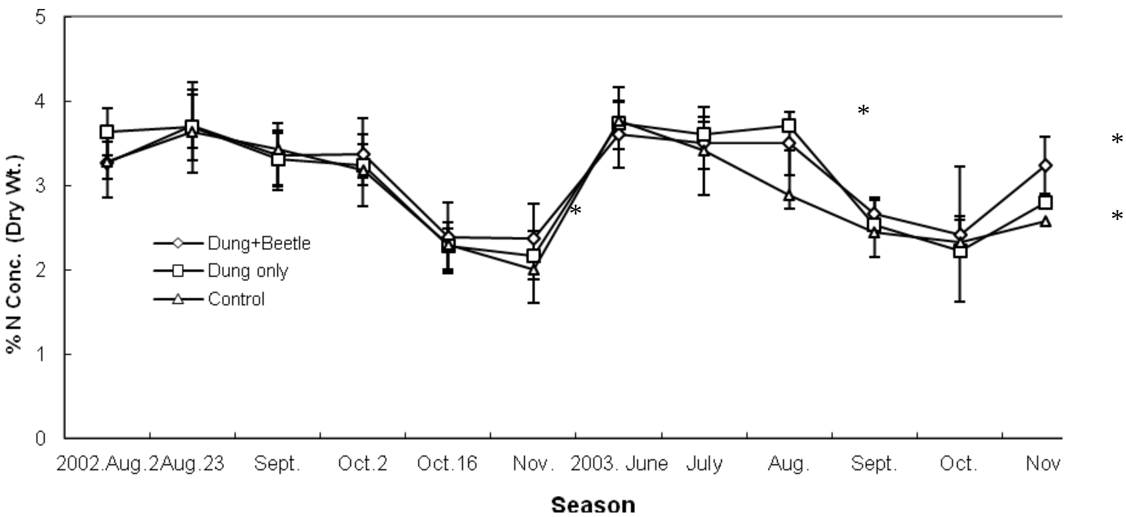


Fig. 2. Comparison of air permeability coefficients of soil cores following 172 days of dung burial activity by paracoprid dung beetles. 'Beetle 1' is *C. ochus*, 'Beetle 2' is *C. tripartitus* and 'Beetle 3' is *O. lenzii*.



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g. 3. Effect of dung beetle on nitrogen content of forage (± S.D.). 'Dung + Beetle' is beetle treatment *C. ochus*, *C. tripartitus* and *O. lenzii*. 'Control' is without dung and dung beetle. Treatments marked with an (*) denote a significant difference from the control. L.S.D. (5%).

2.1.2 Effects of dung beetles on grass properties

Substantial differences in yield were obtained according to different beetle species (Table 1). The total crude protein in shoots increased with *C. ochus* or *C. tripartitus* treatment 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 1). The TDN content of herbage was highest in the *O. lenzii* treatment and lowest in the control. The digestibility dry intake (DDI) and relative feed value (RFV) of herbage 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 herbage properties such as nitrogen surplus on the nutrient feed value.

Table 1. Effects of dung beetle activity on yield and feed value of Perennial ryegrass. TDN (total digestible nutrient), ADF (acid detergent fiber), DDI (digestibility dry intake), RFV (relative feed value) (± S.D.).

Treatment	Yield Tops+ roots (g)	Total crude protein in tops (g)	TDN (%)	ADF (%)	DDI (%)	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 ± 0.40 [ab]	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]

2.1.3 Different effects of three paracoprid dung beetles based on their niche

The organic matter was not significantly different between treatment at 0-5cm depth for three weeks. But, there was significantly higher in the plot containing *O. lenzii* after five weeks (Fig. 4a). At 5-10cm depth, organic matter was the highest in the plot containing *C. ochus* for three weeks to five weeks and *O. lenzii* increase higher after five weeks (Fig. 4b). At 10-30cm depth, *C. ochus* was the highest in organic matter after two to five weeks, but, *O. lenzii* increased after 6 weeks (Fig. 4c). This phenomenon is related to niche differences. *O. lenzii* buried mostly in the top soil layer, *C. ochus* and *C. tripartitus* carried the dung deeper at two different levels. Among the three paracoprid, *C. ochus* convey dung as their food into the deepest depth compare to *C. tripartitus* and *O. lenzii*. Total nitrogen contents are similarly tendency to result of organic matter in each dung beetle. The remained dung ball will be recycled into the soil. In 4 weeks, fungi, actinomycetes, yeast and Gram negative bacteria activity was showed apparently by dung beetles activity according to their niche (Table 2).

Table 2. Microbial response to dung beetles addition to cow dung pot incubation.

Treatment	GN (X 10^3)	F (X 10^3)	AC (X 10^4)	B (X 10^5)
O. lenzii – 1*	92.0 ^{c}	7.0 ^{abc}	9.3 ^{a}	10.0 ^{c}
O. lenzii - 2	5.0 ^{c}	4.0 ^{abc}	1.3 ^{b}	3.0 ^{c}
O. lenzii - 3	12.0 ^{c}	0.7 ^{b}	1.0 ^{b}	6.7 ^{c}
C. ochus - 1	190.0 ^{b}	10.0 ^{ab}	11.0 ^{a}	34.0 ^{b}
C. ochus - 2	112.0 ^{bc}	3.3 ^{bc}	2.3 ^{b}	28.0 ^{b}
C. ochus - 3	747.0 ^{a}	4.0 ^{bc}	2.7 ^{b}	122.0 ^{a}
C.tripartitus - 1	11.3 ^{c}	11.7 ^{a}	0.0 ^{b}	0.7 ^{c}
C.tripartitus - 2	9.0 ^{c}	8.0 ^{abc}	1.3 ^{b}	5.0 ^{c}
C.tripartitus - 3	17.7 ^{c}	10.3 ^{ab}	0.3 ^{b}	2.7 ^{c}
Control –1	0.3 ^{c}	6.3 ^{abc}	0. 0 ^{b}	2.3 ^{c}
Control –2	4.0 ^{c}	0.0 ^{c}	0.0 ^{b}	2.0 ^{c}
Control –3	4.2 ^{c}	0.0 ^{c}	0.0 ^{b}	3.1 ^{c}

GN: Gram negative, F: Fungi, AC: Actinomycetes, B: Aerobic bacteria *1: 0-5 cm, 2: 5-10 cm, 3: 10-30 cm depth.

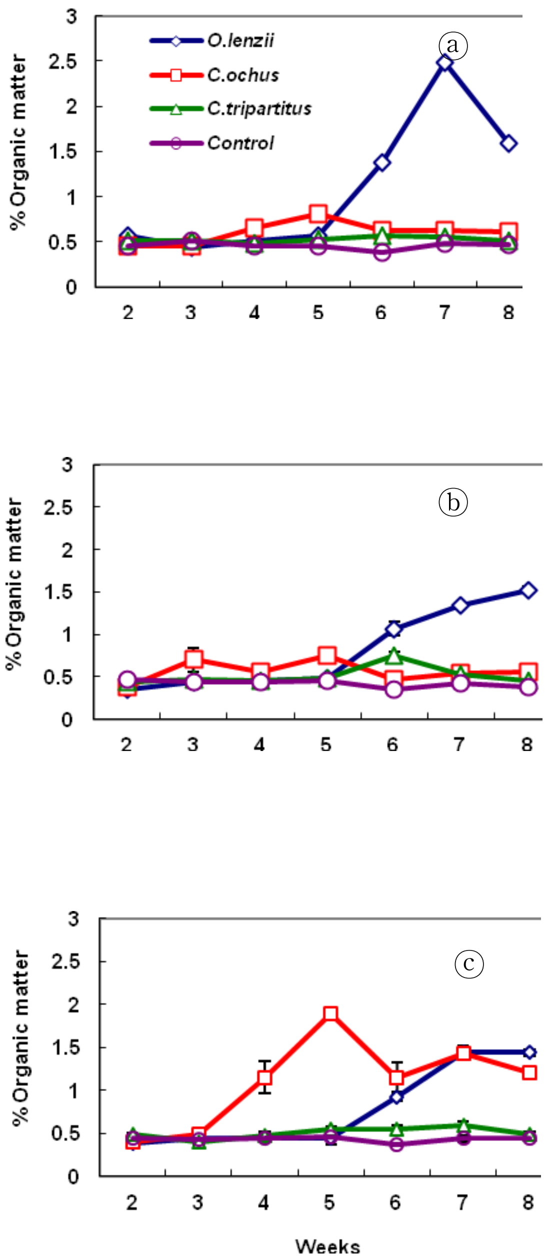

Fig. 4. Changes in concentrations of organic matter of each dung beetle activity in soil layer. a: 0-5 cm, b: 5-10 cm, c: 10-30 cm

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2.1.3 Recycling the nitrogen from dung to the grass

The ^{15}N of grass were significantly different between with and without dung beetles, reflecting the differences in isotopic N composition (Fig. 5). The ^{15}N content of leaves in grass ranges from 3.3 to 4.5%, average 3.9% without dung beetles but, those of dung beetle treatment from 18.4 to 21.8%, average 20%. This means that 16% of ^{15}N was caused by dung beetle activity. This is recovered by dung beetles. As dung beetle conveyed dung into the soil and then grass uptake ^{15}N from the soil. From this result, we understood that dung beetles affect on N contents increasing of grass.

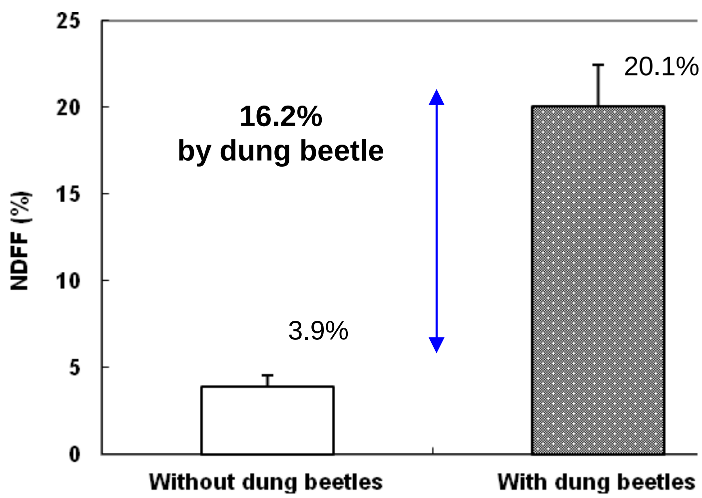

Fig. 5. ^{15}N content of leaves in grass with and without dung beetles.

3. Interaction between earthworms and dung beetles

The effect of earthworm and dung beetle on cattle dung pat decomposition was assessed by combining quantification of earthworm density and with or without dung beetle in pats and measurements of the decomposition rate of these pats. Cattle dung decomposition rate was higher in the pots treated with both earthworm and dung beetle than in the pots with either earthworm or beetle alone (Table 3). After dung beetle and earthworm activity, the growth of oat in earthworm with dung beetle treatment was similar effect with fertilizer treatment. Dung beetle was responsible for dung decomposition until 78% moisture content in the dung, earthworm was responsible for up to 30% moisture of dung, and two group were not shown any activity for decomposition less 30% moisture content of dung (Fig. 6). Therefore dung in the different periods could be broken down by each group. The disappearance and conveyance of dung by earthworm and dung beetle was 72% of the initial dung amount. 10.2% of 72% dung was used making brood balls by dung beetle. Earthworms activity were not an impediment on making brood balls by dung beetles (Fig .7).

Table 3. Decomposition rate by earthworm density and dung beetle in non-breeding and breeding season

	Decomposition rate(%)					
	E5*	E10	E20	DB	E5+DB	E10+DB
Breeding season	47.35 ±4.54[bc]	40.15 ±6.92[bc]	51.77 ±9.38[b]	71.95 ±4.49[a]	56.06 ±10.23[ab]	71.92 ±14.72[a]
Non-breeding season	45.01 ±4.56[b**]	48.64 ±5.80[b]	51.99 ±7.73[ab]	61.15 ±10.41[ab]	69.93 ±9.73[a]	72.60 ±16.90[a]

* E5: 5 earthworms, E10: 10 earthworms, E20: 20 earthworms, DB: dung beetle, E5+DB: 5 earthworms with one pair dung beetle, E10+DB: 10 earthworms with one pair dung beetle ** Mean followed by the same letter in row are not significantly different (P<0.05; Tukey's test[SYSTAT 9.0])

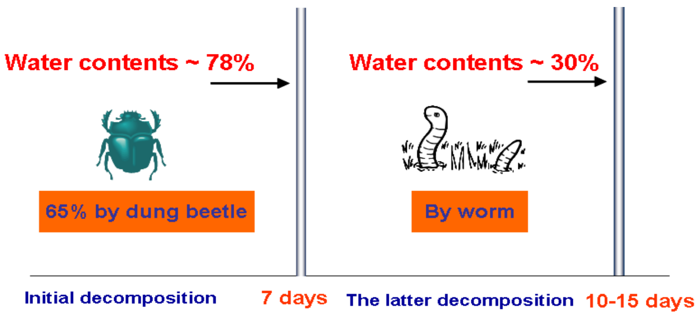

Fig. 6. Water contents of dung during decomposition periods until 7 days and 15 days after putting two coprophagus invertebrates in the pot and the role of two coprophagus invertebrates in different decomposition periods.

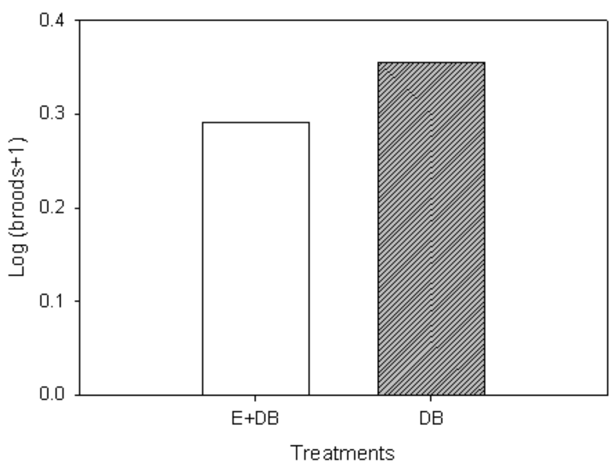

Fig. 7. Effect on brood balls production in dung beetle with earthworm and in dung beetle treatment. E+DB: 5 or 10 earthworm with one pair of dung beetle, DB: one pair of dung beetles x^2=0.37 P=0.54.

Conclusion

From result of this experiment, three paracoprid dung beetles burrow into dung on beneath in the soil allowing increase organic matter and total nitrogen contents and microorganism activity. After being affected by dung beetles, organic N was transferred to the underlying soil as sources of C and N for microorganisms. Mineralization is dominant in this process and is accompanied by nitrification. These date indicate that the organic matters and total nitrogen increased as beetle activity increased thus organic matter and total nitrogen contents in each depth were positively correlated with each depth microbial activity. Three paracoprid dung beetles (*C. ochus, C. tripartitus* and *O. lenzii*) can be found in summer season in the field. Therefore, three dung beetles are not enable to compete severely in same dung unless differ their ecological niche according to in soil depth. The competition in same patch is mitigated by having different nesting period and they are evitable to compete by different soil layer although they have same feeding period. To avoid their food competition, they have different niche as like as habitat selection, dial activity and seasonality. *C. ochus* have nesting period during autumn season on the contrast, *C. tripartitus* have a early summer season. As a result, large amount of dung was conveyed under the soil by their spatial distribution. Different species use dung each season. Finally, this is related with their life strategy. In conclusion, the data reported here indicate that herbage feed-value and herbage yield was increased by dung burial and the consequent fertilizing effect of beetle and earthworm activity. The interaction of earthworms and dung beetles may have a complementary cooperation rather than competition in the same dung pat. Indeed, the developments of earthworm accelerate to coexist with dung beetles instead without dung beetles. For maximum benefits of the effective earthworms and dung beetles can be achieved, it is needed to preserve population of earthworm and dung beetles farmland for sustainable agricultural environment.

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