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ORIGINAL ARTICLES

Soil nutrient as affected by activity of dung beetles, *Scarabaeus sacer* (Coleoptera: Scarabaeidae) and toxicity of certain herbicides on beetles

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ABSTRACT

Soil content of some nutrients as affected by the activity of dung beetles, *Scarabaeus sacer* (Coleoptera:Scarabaeidae) was determined. Two sizes of dung beetles were considered, large and small beetles measuring 35mm and 20 mm in length, respectively, as well as the number of beetles included in the soil mixed dung. Generally, the activity of dung beetles in the soil mixed with dung increased nitrogen, phosphorous, potassium, calcium and magnesium content. These nutrients were always higher in the presence of dung beetles as compared to the control (where no beetles were placed in the soil). Also, large dung beetles were more effective than small beetles in increasing soil nutrients and the fewer the number of pairs in the tested soil led to a higher level of nutrients than the addition of more pair. Furthermore, soil contents of nitrogen, phosphorus and potassium was highest after 7 days from initiation of the experiment and then gradually decreased in the following investigation. Meanwhile, soil content of calcium and magnesium was relatively stable and insignificantly affected with time. The toxic effect of four herbicides on *S. sacer* was determined. No toxic effect was observed when fresh dung was sprayed with Betanal Expert or Nicosulfuron at their recommended doses. Meanwhile, 100% mortalities of dung beetles were recorded when fresh dung was treated with Propaquizafop and Oxadiazon herbicides at recommended doses.

Key words: Dung beetles, *Scarabaeus sacer*, Soil nutrients, Herbicides

Introduction

Dung beetles in the subfamily Scarabaeinae (Coleoptera:Scarabaeidae) have important ecological roles related to nutrient cycling, decomposition, seed dispersal, soil fertilization and aeration (Wilson, 1998; Miranda *et al.*, 2000 and Numa *et al*., 2012). Dung beetles exhibit many forms of nesting behavior, including dwelling (endocoprid), rolling (telecoprid) and tunneling (paracoprid) (Halffter and Edmonds, 1982).

The beneficial effects of cattle dung to grassland ecosystems have been well documented (Bornemissza, 1960). Dung can contain between 1-3% nitrogen by weight (Macqueen & Beirne, 1975 and Mittal, 1993), in every 100 kg of dry cattle dung there was 0.82 kg of phosphorus and 2.7 kg of nitrogen (William and Haynes, 1995). Approximately 80% of the nitrogen content in sheep and cattle dung denature by bacteria and volatilization when left on the pasture surface (Gillard, 1967). Several studies have shown that grass growth was benefited when the nutrients present in dung was quickly recycled within the pasture ecosystem by dung beetles (Bornemissza, 1960 & Holter, 1977 and 1979).

Pesticide formulations have a greater effect on beetles if the insecticide was in the manure. Parasiticides in the macrocyclic lactone class, i.e. abamectin, ivermectin, eprinomectin and doramectin, kill flies and dung beetles in the manure (Fincher, 1992; Holter *et al.*, 1994; Floate, 1998; Lumaret & Errouissi, 2002). Blume *et al.* (1974) found that cattle fed methoprene at a rate of 1 mg/kg produced dung that reduced *Onthophagus gazella* survival by 1.8% the day after treatment and by 32.6% by the 5th day. Furthermore, as little as 5 ppm of methoprene (52.5% EC) mixed directly into dung could cause 33.3% mortality to *O. gazella*.

the present study was carried out to determine if the activity of dung beetle *Scarabaeus sacer* affected soil content of five main soil nutrients. Furthermore, the toxicity of four commonly used herbicides was determined on *S. sacer* beetles.

Material and Methods

The present study was conducted at the Department of Plant Protection at Faculty of Agriculture, Ain Shams University.

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Maintanence of the dung beetle Scarabaeus sacer:

The stock culture of *S. sacer* adult beetles were collected from Abo-Rawash region at Giza Governorate (Fig.1), the beetles were placed in plastic boxes filled with soil containing an equal ratio of sand and clay, which was kept always moist. Fresh cattle dung obtained from the field of Faculty of Agriculture, Ain Shams University, at Shalakan, Qualyobia Governorate was placed on the surface of the soil.

Fig. 1: Culture of dung beetles , *S. sacer* collected from Abo-Rawash region.

Effect of S. sacer on soil nutrients:

To evaluate the effect of *S. sacer* on soil contents of five major nutrients namely, nitrogen, phosphorous, potassium, calcium and magnesium, plastic trays measuring 18 x 18 cm and 15cm in depth were filled with 3 kg of soil at a ratio of 1:1 sand: clay. Fresh cattle dung weighing 250 g was place on top of the soil. Subsequently, young *S. sacer* beetles were collected from the stock culture and according to their size divided into two groups. The first group comprised large beetles which measured approximately 35 mm in length, the second group comprised the smaller sized beetles measuring approximately 20 mm in length.

The trays containing soil and fresh dung were divided into groups of five treatments and into each group of trays 2, 4, 6, 8 or 10 *S. sacer* adult male and female beetles (1:1) were introduced. This procedure was carried out for each of large and small sized beetles. The trays were covered with muslin mesh to prevent escape of the insects. Each treatment was replicated 3 times. Similar trays were prepared as a control where no beetles were introduced. The trays were maintained in the laboratory at room temperature of 33 ± 3° C and 65± 3 % RH.

Soil analysis:

After 7, 14 and 21 days from introduction of dung beetles, a random soil sample weighing 200 g was collected from each tray and analyzed for its content of nitrogen, phosphorous, potassium, calcium and magnesium according to the method described by Page *et al*. (1982). Data obtained were submitted to analysis of variance (ANOVA) using F test and means were compared by Tukey's Standardized Range Test at 0 05 probability level.

Toxic effects of four herbicides on S. sacer:

The toxic effect of four commercial herbicides was determined on adult *S. sacer* beetles.

Herbicides tested:

1- Betanal Expert (Phenmedipham 9.1% + Desmedipham 7.1%+ Ethofumesate 11.2%) EC: Applied at 1000ml/ feddan.
2- Nicosulfuron 70 % WDG: Recommended application of 35 g/feddan.
3- Propaquizafop 10% EC (damex-D): Recommended application of 350 ml/feddan
4- Oxadiazon 12 % EC (doxar) : Recommended application of 2500 ml / feddan

Effect of herbicides on activation of dung beetles, S. sacer:

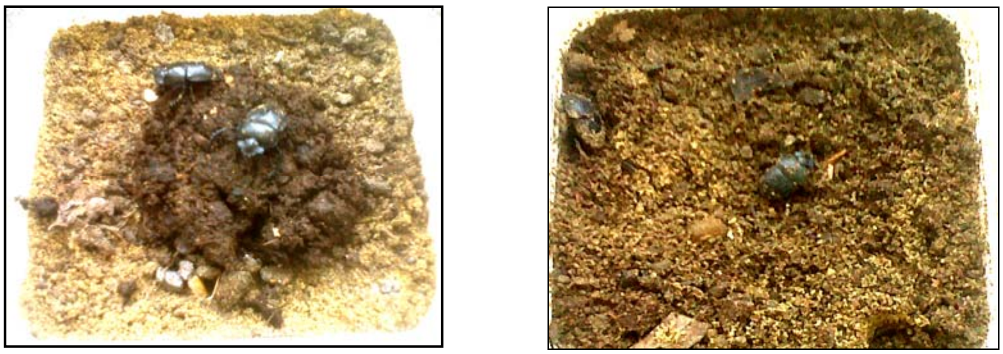
Three replicates each comprising ten plastic trays were prepared as previously described and each filled with a mixture clay and sand soil at a ratio of 1:1. Each herbicide was sprayed and mixed with fresh dung at their recommended dose. Subsequently, 250gm of fresh dung was added on the surface of the soil for each replicate with one pair of large dung beetles. Plastic cups were covered with mesh nets to prevent beetle escape.

The plastic cups were kept in room temperature (65% RH and 35° C) and examined after 3, 7 and 10 days to determined the activity of *S. sacer*, beetles.

Results:

Effect of S. sacer activity on soil nutrient:

The activity of roller dung beetle *S.sacer* in the transfer of deposited dung below the soil surface physically relocates organic material in the soil layers (Fig. 2). Nitrogen, phosphorous, potassium, calcium and magnesium content in soil mixed with dung were always higher in the presence of *S. sacer* beetles than when no beetles were present (i.e. control). Furthermore, the inclusion of a fewer number of beetles led to a higher increase in soil nutrient content than when the number of beetles was increased. In addition, activity of larger beetles had a stronger impact on nutrient content in the soil mixed dung than smaller sized beetles.



(A) **(B)**

Fig. 2: Burial of dung by roller dung beetles, *S. sacer*.

1- Nitrogen content in soil mixed with dung:

Nitrogen content in the control, (i.e when no dung beetles were included in the soil mixed dung), was 660 mg/ kg after 7 days from the initiation of the experiment. As seen in Table 1, the presence of *S. sacer* in the soil mixed with dung led to an increase in nitrogen soil content. This effect was most apparent at the first investigation, i.e. 7th day following the initiation of the experiment but then gradually decreased with time. Furthermore, the lower number of beetles had a stronger impact in increasing soil nitrogen content. Generally, larger beetles had a stronger effect in increasing nitrogen content than smaller beetles.

At the 1st investigation, the highest mean of nitrogen soil content was recorded when one pair of *S.sacer* beetles were considered, being 1079.3 mg/kg which was reduced to 766.3 mg/ kg on the 2nd investigation (i.e. 14 days). This value was slightly decreased to 730 mg/kg after 21 days. Compared to the presence of one pair, nitrogen content was slightly lower when 2 and 3 pairs of beetles were placed in the soil mixed with dung, being 1039.3 and 1007.7 mg/ kg, respectively. There was a gradual similar decrease in the following days to reach 626 and 629.7 mg/ kg, respectively, at the termination of the experiment (i.e. 21 days). Lowest nitrogen content was recorded when 5 pairs were placed in the soil mixed dung, as it was 780 mg/ kg after 7 days to reach a low of 474 mg/ kg after 21 days.

When small sized *S.sacer* were tested, nitrogen soil content was at all times less than that recorded for the larger beetles but it followed the same trend. The highest and lowest means of nitrogen soil content was 856.7 and 668 mg/kg in treatments including one and 5 pairs of beetles, respectively at the 1st investigation conducted on the 7th day from the start of the experiment. These values gradually decreased to reach a low of 565 and 409 mg/ kg , respectively after 21 days.

2- Phosphorous content in soil mixed with dung:

As shown in Table 2, the presence of *S.sacer* in the tested soil increased phosphorous soil content than in the soil mixed dung with the absence of beetles and this effect was more apparent when large beetles were tested than smaller beetles. The highest recorded mean of phosphorous soil content was 17.5 mg/ kg when one pair of large beetles was placed in the soil mixed dung as compared to 10.1 mg/ kg in the control. It is of interest to note that the presence of 2 or 2 pairs had a similar effect on phosphorous content, as it was 15.7 and 15.1 mg/ kg, respectively, which was only slightly less than that recorded when only one pair of beetles were added. It is also

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noteworthy, that after 14 days the phosphorous content was comparable when 1, 2, 3, 4 or 5 pairs of large beetles were placed in the soil, as it ranged between 11.6 - 12.5 mg/ kg. This observation was also exhibited when smaller beetles were considered as phosphorous content ranged between and 10.3 -11.6 mg/ kg.

After 21 days, phosphorous content decreased than those recorded at the previous investigation, (Table 2).

3- Potassium content in soil mixed with dung:

As seen in Table 3, in the control potassium content was 687.7 mg/ kg, the presence of one pair of *S.sacer* large beetles in soil mixed dung increased potassium content to 1127.7 mg/ kg which was more than 1.5 times it's content in the control after 7 days from the start of the experiment. Potassium content decreased gradually in the subsequent investigation to reach 830.3 mg/ kg, which was nearly 1.5 times it content at the final investigation (i.e. 21 days). Potassium soil content was 823.3 mg/ kg in the presence of 2 pairs in the soil after 21 days which was comparable to that recorded when one pair was considered in the soil, (Table 3). Potassium content in soil treated with dung was not affected when either 4 or 5 pairs of *S.sacer* beetles were included. It was 828.7 and 688.7 mg/ kg after 7 and 21 days, respectively when 4 pairs of large beetles and 823.7 and 710 mg/ kg, respectively when 5 pairs of large beetles were considered at the respective mentioned investigations. This observation was also valid when the experiment was conducted on small sized beetle, (Table 3).

4- Calcium content in soil mixed with dung:

Mean calcium content was higher in the presence of one pair of *S. sacer* beetles in the soil mixed dung and gradually decrease with the increase in the number of *S. sacer* pairs included in the soil. As seen in Table 4, calcium content was similar between investigations conducted after 7, 14 and 21 days in soil mixed dung comprising 2, 3 or 4 pairs *S. sacer* beetles either large or small.

5- Magnesium content in soil mixed with dung:

The highest mean of magnesium soil content was 980 mg/ kg, after 7 days, in the presence of one pair of *S. scaer* beetles in the soil treated with dung. This content was reduced to 786 mg/ kg after 14 days but remained at approximately the same level at the last investigation on the 21st day, (Table 5). Magnesium content gradually decreased in the presence of 2, 3 or 4 pairs of beetles and was less than that recorded for one pair. It is noteworthy that in each of these cases, magnesium content was approximately the same after 7 or 14 days following the initiation of the experiment (Table 5). However, after 21 days it increased to 766.7, 714.3 and 711.3 mg/ kg in dung mixed soil in the presence of 2, 3 and 4 pairs of beetles, which shows that number of included beetles had very little impact on magnesium content. Furthermore, this value was relatively comparable to those recorded when one pair were considered in the experiment i.e. 780.7 mg/ kg.

The presence of 5 pairs of large beetles in soil mixed with dung had no effect on magnesium content after 7 and 14 days, being 571 and 547 mg/ kg respectively. However, unlike the presence of lesser number of beetles after 21 days magnesium content was reduced to 451.7 mg/ kg.

The activity of one pair of smaller sized *S. sacer* beetles did not affect magnesium content in the soil mixed dung after 7 and 14 days, being 691, 684 mg/ kg. However, this content mildly increased to 724.3 mg/ kg after 21 days. In the presence of 2 pairs of beetles very slight increase in magnesium content occurred increasing from 621 mg/ kg after 7 days to 646.3 then to 679.7 mg/ kg after 14 and 21 days, respectively. Meanwhile in the presence of 4 pairs, magnesium content in the soil remained relatively constant, (Table 5). These results confirm the previous observation that either large or small *S. sacer* beetles had little impact on magnesium content in soil mixed dung.

Table 1: Effect of rolling dung beetles, *Scarabaeus sacer* on nitrogen (N) soil nutrient content.

Number of beetles	Means of nitrogen(N) soil content (mg/kg soil ±SD)					
	After one week		After two weeks		After three weeks	
	Large beetles	Small beetles	Large beetles	Small beetles	Large beetles	Small beetles
One pair	1079.3 ^{a}±11.2	856.7 ^{c}±6.1	766.3 ^{a}±10.0	698.7 ^{b}±6.8	730.0 ^{a}±5.5	565.0 ^{c}±5.6
Two pairs	1039.3 ^{ab}±10.0	838.0 ^{c}±7.2	677.7 ^{cb}±6.7	651.3 ^{cde}±18.6	626.0 ^{b}±6.3	513.0 ^{d}±6.1
Three pairs	1007.7^{ab}±12.5	773.3^{de}±15.3	658.7 ^{d}±7.6	647.7 ^{de}±5.9	629.7 ^{b}±9.6	469.0 ^{ef}±6.6
Four pairs	851.7^{c}±11.5	720.3 ^{ef} ±10.0	636.3 ^{def}±17.2	623.0 ^{ef}±4.4	607.3 ^{b}±3.5	442.7 ^{f} ±5.5
Five pairs	780 ^{d} ±12.5	668.0 ^{f} ±14.8	648.7 ^{cde}±5.9	611.7 ^{f}±9.1	474.0 ^{e}±4.7	409.3 ^{g}±6.3
Control (no beetles)	660.0±4.2		610.7±7.3		402.3±6.1	
F value (interaction between treatment and size of beetles)	12.1		11.81		39.15	

Means with the same letter not significantly different

Table 2: Effect of rolling dung beetles, *Scarabaeus sacer* on phosphorus (P) soil nutrient content.

Number of beetles	Means of phosphorus (P) soil content (mg/kg soil ±SD)					
	After one week		After two weeks		After three weeks	
	Large beetles	Small beetles	Large beetles	Small beetles	Large beetles	Small beetles
One pair	17.5^{a}±1.2	12.8^{cd}±0.3	12.5^{a}±0.4	11.6^{bc}±0.3	11.4^{a}±0.3	9.5^{cb}±0.4
Two pairs	15.7^{b}±0.3	12.5^{cde}±0.2	12.3^{a}±0.2	11.1^{cd}±0.1	9.8^{b}±0.3	8.4^{de}±0.2
Three pairs	15.1^{b}±0.2	11.7^{def}±0.2	12.1^{ab}±0.2	10.8^{de}±0.1	9.5^{b}±0.3	8.3^{de}±0.3
Four pairs	13.7^{c}±0.3	10.6^{fg}±0.2	11.9^{ab}±0.2	10.7^{de}±0.2	8.6^{cd}±0.5	7.7^{e}±0.2
Five pairs	11.3^{efg}±0.3	10.5^{fg}±0.2	11.6^{bc}±0.4	10.3^{e}±0.2	8.4^{de}±0.2	7.5^{e}±0.3
Control (no beetles)	10.1±0.2		10.2±0.4		6.4±0.4	
F value (interaction between treatment and size of beetles)	11.2		10.6		12.7	

Means with the same letter not significantly different

Table 3: Effect of rolling dung beetles, *Scarabaeus sacer* on potassium (K) soil nutrient content.

Number of beetles	Means of potassium (K) soil nutrient content (mg/kg soil ±SD)					
	After one week		After two weeks		After three weeks	
	Large beetles	Small beetles	Large beetles	Small beetles	Large beetles	Small beetles
One pair	1127.7^{a}±5.9	930.0^{c}±8.2	958.0^{a}±13.5	872.0^{b}±5.3	830.3^{a}±10.0	754.3^{c}±10.7
Two pairs	989.0^{b}±5.6	839.7^{d}±8.1	879.0^{b}±8.5	854.3^{b}±4.5	823.3^{a}±11.3	724.7^{cd}±5.0
Three pairs	906.7^{c} ±14.2	766.3^{e}±5.7	821.7^{bc}±2.1	739.0^{de}±6.3	789.3^{b}±7.4	712.0^{de}±2.0
Four pairs	828.7^{d}±6.8	727.3^{ef}±14.8	754.0^{de}±12.2	736.0^{de}±6.0	688.7^{e}±8.1	690.0^{e}±7.9
Five pairs	823.7^{d}±5.0	720.0^{ef}±6.8	789.3^{cd}±8.0	715.0^{e}±5.0	710.3^{de}±9.6	645.3^{f}±11.6
Control (no beetles)	687.7±5.3		710.7±6.4		640.3±5.1	
F value (interaction between treatment and size of beetles)	15.1		14.15		20.5	

Means with the same letter not significantly different

Table 4: Effect of rolling dung beetles, *Scarabaeus sacer* on calcium (Ca) soil nutrient content.

Number of beetles	Means of calcium (Ca) soil nutrient content (mg/kg soil ±SD)					
	After one week		After two weeks		After three weeks	
	Large beetles	Small beetles	Large beetles	Small beetles	Large beetles	Small beetles
One pair	5351.3^{a} ±11.5	4834.3^{b} ±14.1	4621.3^{a} ±12.5	4285.0^{cd} ±16.4	5188.3^{a} ±10.2	4663.3^{b} ±14.2
Two pairs	4613.0^{c} ±12.6	3948.3^{e} ±12.2	4454.0^{b} ±15.7	4103.3^{ef} ±13.8	4321.0^{c} ±12.1	4211.0^{c} ±10.7
Three pairs	4525.7^{c} ±12.5	3849.0^{e} ±8.2	4342.0^{cb} ±14.8	3975.0^{fg} ±11.4	4313.0^{c} ±2.6	3897.0^{d} ±4.5
Four pairs	4345.3^{d} ±41.0	3526.7^{f} ±13.1	4144.7^{de} ±11.4	3860.3^{gh} ±10.5	4282.0^{c} ±19.7	3877.3^{d} ±18.2
Five pairs	4275.3^{d}±13.4	3380.3^{g}±12.6	4129.0^{e} ±12.4	3725.3^{h} ±10.8	3858.3^{d} ±15.1	3813.3^{d} ±15.3
Control (no beetles)	3251.3±10.1		3631.0±10.9		3651.3±10.1	
F value (interaction between treatment and size of beetles)	16.0		11.13		16.0	

Means with the same letter not significantly different

Table 5: Effect of rolling dung beetles, *Scarabaeus sacer* on magnesium (Mg) soil nutrient content.

Number of beetles	Means of magnesium soil nutrient content (mg/kg soil ±SD)					
	After one week		After two weeks		After three weeks	
	Large beetles	Small beetles	Large beetles	Small beetles	Large beetles	Small beetles
One pair	950.0^{a}±4.2	691.0^{c}±7.5	786.0^{a}±6.6	684.0^{b}±9.8	780.7^{a}±2.1	724.3^{b}±5.9
Two pairs	789.7^{b}±8.1	621.0^{d}±9.5	703.3^{b}±4.9	646.3^{c}±7.6	766.7^{a}±4.9	679.7^{c}±7.6
Three pairs	645.0^{d}±7.0	577.0^{e}±14.7	688.7^{b}±9.6	587.7^{d}±6.8	714.3^{b}±12.5	588.0^{d}±6.2
Four pairs	588.3^{e}±4.7	524.0^{f}±10.0	588.3^{d}±8.5	537.0^{ef}±6.1	711.3^{b}±1.5	523.3^{e}±3.1
Five pairs	571.7^{e}±10.6	484.0^{g} ±7.2	547.3^{e}±11.8	521.7^{f}±10.6	451.7^{f}±1.5	413.0^{g}±2.0
Control (no beetles)	447.7±2.1		513.3±5.3		401.0±5.4	
F value (interaction between treatment and size of beetles)	90.3		23.02		40.5	

Means with the same letter not significantly different

Toxic effect of herbicides on dung beetles, S. sacer:

Fresh dung sprayed at the recommended dose with the herbicides Betanal Expert or Nicosulfuron showed no toxic effect on activity of *S. sacer* after 3, 7 or 10 days. Meanwhile, dung treated with either Propaquizafop or Oxadiazon herbicides, caused 100% mortality to dung beetles on the 3rd day following treatment.

Discussion:

Statistical analysis of the present work exhibited significant differences between interactions of dung beetles size (large and small) and number of beetles considered in the soil mixed with dung. Several authors have reported an increase in soil nutrients (P, K, N, Ca and Mg) found in soils exposed to dung beetle activity in experimental dung masses (Galbiati *et al.*, 1995; Bertone, 2004; Lastro, 2006; Yamada *et al*., 2007). Yamada *et* *al.* (2007) report a significant positive relationship between the magnitude of released inorganic N and available P and K in cattle dung and dung beetle abundance. Increase in soil nutrients as a result of dung beetles activity was reported by Yokoyama *et al*. (1991) to enhance soil fertility by increasing nitrogen available for uptake by plants through mineralization. Studies of the present work showed that nutrient content in the soil was markedly more than in soil without dung beetles. Furthermore, an increase in the number of dung beetles *S. sacer*, led to a reduced amount of nitrogen, phosphorous and potassium soil content as compared with that comprising a fewer number of dung beetles. Yokoyama *et al*. (1991) reported that nitrogen in the soil under the cow dung where tunneled beetles was released was significantly greater than that under the control dung without dung beetles. Such an observation was explained by Gillard (1967) who found that the presence of dung beetles prevent the loss of nitrogen through ammonia volatilization by burying dung under the soil surface. Furthermore, when adequate dung beetle numbers were present to bury dung, nitrogen loss was markedly reduced. In a controlled study five pairs of dung beetles *Onthophagus nuchicornis* L. buried 37% of each dung pat, which when applied to pasture scale was a calculated return of 134 kg of nitrogen per hectare (Macqueen and Beirne, 1975). .

Gillard (1967) stated that 80% of the nitrogen content of dung was denatured by bacteria and lost by volatilization when sheep and cattle dung remains on the pasture surface. A FAO report estimates that 12 of 30 million tons of nitrogen excreted by extensive livestock production systems in the mid-1990s were lost through NH3 volatilization (Steinfeld *et al.,* 2006). By burying dung under the soil surface, dung beetles prevent the loss of N through ammonia (NH3) volatilization (Gillard, 1967), and enhance soil fertility by increasing N available for uptake by plants through mineralization (Yokoyama *et al*., 1991).

Results of the present investigation showed that magnesium and calcium content in the soil mixed with dung was higher as a result of *S. sacer* activity as compared to soil mixed with dung but with the absence of dung beetles. However, increase in magnesium and calcium content was relatively unaffected by the number of beetles included in the tested soil mixed with dung. Bertone *et al*. (2006) recorded significant increases of Mg in soil as a result of *O. gazella* and *O. taurus* activity.

The effect of the four considered herbicides on dung beetles was some what expected . Betanal Expert or Nicosulfuron are a selective systemic herbicides which are absorbed through the leaves shoots and roots. Meanwhile, Propaquizafos is a systemic post-emergence herbicides which is absorbed through the foliage or roots and Oxadiazon is a selective contact herbicides, both caused 100% mortality to dung beetles on th 3^{rd} day following treatment. Treatment of cattle with veterinary parasiticides and insecticides, residues are excreted into the dung in concentrations that may be toxic to functionally important dung-colonizing insects (Wall and Beynon, 2012). Manure excreted by cattle treated with a pour-on pyrethroid was toxic to dung beetles for 1 week following treatment (Kruger *et al*., 1999). Persistent use of these compounds will have a long-term negative impact on the dung beetle population. In contrast, moxidectin is less toxic to dung beetles and did not reduce dung beetle survival (Fincher and Wang, 1992; Lumaret and Errouissi, 2002).

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