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ECOLOGICAL ROLE OF *ONTHOPHAGUS TAURUS* (SCHREBER) IN SOIL NUTRIENT MOBILIZATION

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ABSTRACT

Dung beetles play a major role in the pasture ecosystem. The manure recycling activity of dung beetles is linked to their tunneling behavior. The present study was designed to analyze the tunnel pattern and nutrient mobilization by dung beetles, *Onthophagus taurus* (Schereber, 1759) in different soil types. A simple type of tunnel pattern was observed in all the four types of soil after 30th day of their introduction (10 pairs of male and female) into the experimental setup. However, the maximum number of tunnels was observed in the sandy and sandy clay loam (no. of openings- 15), followed by loamy soil (no. of openings- 13). The physical (texture, water holding capacity, porosity, moisture content) and chemical parameters (pH and nutrients) of all the four types of soils were evaluated. Soil texture analysis revealed the texture to be of sandy (yellow soil), sandy clay loam (red and black soil), and loamy sand (brown soil) types. Water holding capacity and the soil porosity were recorded highest in the sandy soil, whereas moisture content was found maximum in the sandy clay loam. Soil nutrient analysis illustrated a significant increase in the amount of nitrogen (N), phosphorus (P), calcium (Ca), sulfur (S), sodium (Na), potassium (K), organic carbon and organic matter. Thus, the present study confirms that tunneling activity of *O. taurus* enhances the soil nutrients by carrying out dung decomposition.

Key words: Dung beetle, *Onthophagus taurus*, nesting, tunneling, nutrients, soil parameters, texture, water holding capacity, porosity, moisture, nutrients, sandy, clay, loam, red and black soils

Arthropods are one of the most successful and cosmopolitan group of animals on earth. Their ability to adapt to the changing environment makes them the most successful and diverse group of animals (Giribet, 2019). Among the arthropods, class Insecta is the largest group and the order Coleoptera is the leading order of the animal kingdom constituting almost 25% of all the living organisms and it includes around 3,50,000 species worldwide and among these around 15,088 species are present in India. Among 25% of insect species, 40% are beetles (Thakkar, 2016). Scarab beetles commonly known as dung beetles of the family Scarabaeidae have approximately 30,000 species of beetles (Cajaiba et al*.,* 2017). They exhibit a wide range of ecological, morphological as well as behavioral adaptations which makes them universally distributed. Mostly dung beetles prefer to be omnivore, than herbivore dung, and the least preferred is carnivore dung (Frank et al., 2017, unpublished data). Mandibles and maxillae of adult dung beetles have a fine outer edge which helps in modifying and filtering out the content of dung (Shukla et al*.,* 2016). Further, tibia of forelegs have spines and spurs which helps them in digging and forming the tunnel. Tibial spur number varies among the species which helps taxonomist to classify the dung beetles (Linz et al*.,* 2019). In addition, head of the dung beetles has a hard, scoop like structure which helps in rolling the dung balls for their nesting (Ix-Balam et al*.,* 2018). *Onthophagus taurus* (Schreber), as a tunneler makes “multimedia galleries” (tunnels) deep into the soil for laying eggs in the brood balls. These tunnels can be formed by both male and female or only by single parent. Brood balls are placed into the blind end of the tunnel. Single branch of these complex tunnels may contain one or multiple brood balls (Tonelli, 2021). This behavioral aspect enhances their ecological efficiency for dung decomposition, bioturbation, seed dispersal, parasite suppression, fly control and nutrient recycling (Shahabuddin et al., 2017). Further, tunneling activity makes the continuous movement of the soil and thereby increases soil aeration and its water holding capacity (Nichols et al*.,* 2008; Doube, 2018). Dung produced by livestock are source of many greenhouse gases such as nitrous oxide (N_2O), methane (CH_4), and carbon dioxide (CO_2) which is reduced by dung beetles by reducing organic matter from the dung by their relocation into the soil (Piccini et al*.,* 2017).

There are generally four types of soil present in nature; sandy, clay, silt and loamy with varying size and texture. Reviews suggest that Vadodara, Gujarat has different types of soil which includes clay, clayey sand, gravel, sand, silt and silt sand (Sabhaya et al., 2018). Although the dung beetles play an important part in agroecosystem, no study has been conducted on the role of dung beetles in the nutrient mobilization in varying soil types of Vadodara district. *O. taurus* is widely distributed in many parts of the country (Sabu et al., 2011; Chandra et al., 2012; Pawara et al., 2012; Gupta et al., 2014; Thakkar and Parikh, 2016), including Vadodara (Singhal et al., 2018) city of Gujarat, making them a suitable model for the study. Hence, in the present work, an attempt is made to elucidate the behavioral and ecological role of *O. taurus* in soil nutrient mobilization.

MATERIALS AND METHODS

Onthophagus taurus along with the surrounding soil and dung was collected by hand pick method from Channi (22.363˚N, 73.166˚E), Kelanpur (22.241˚N, 73.269˚E), Sindhrot (22.331˚N, 73.063˚E), and Timbi (23.149˚7N, 74.002˚E) of Vadodara district. The collection was done during the dawn and dusk, from June to November, during 2021-2022. Identification of the species was done using standard taxonomic keys (Arrow, 1931; Balthasar, 1963; Chandra and Gupta, 2013) and comparing it with the specimens in laboratory, in the Department of Zoology. Four soils collected were sandy (yellow), sandy clay loam (red and black) and loamy sand (brown). Initial identification of soil was done based on colour which was further confirmed from texture analysis using standard guide (Maiti, 2003). The experimental setup was maintained in the laboratory condition where earthen pots (40 cm high, 20 l) were used half filled with yellow, red, black and brown soil and with release of 10 pairs (male and female) in each pot. Laboratory conditions (28ºC, 70% RH, 10:12 hr light regime were maintained. Soil conditions were checked at regular interval using the hygrometer (HTC-2, India) (Pandya et al., 2022). Fresh dung of buffalo was collected with the help of showel from the same site of beetle's collection and a 250 g was provided at regular intervals. The pots were covered with muslin cloth and the setup was maintained for 30 days to observe the tunnels. The dung beetle's rate of reproduction, brood ball formation and tunneling activity were observed to be increases from 20 days onwards with maximum being after 30 days (Pandya et al., 2022).

Therefore, tunnel pattern was monitored by studying its lifecycle and the number of brood balls formed at the end of 30th day, and brood morphometry of each developing stage were recorded. At the end of 30th day, tunnels were filled with the plaster of Paris up to the opening and were allowed to solidify. After 24 hr, the solidified tunnels were excavated carefully from the soil and dimensions of the cast were measured following Sinha (2014). First, the physical parameters (soil texture, water holding capacity, moisture content and porosity) as well as chemical parameters (pH) of all four soils were analyzed (Saxena, 2001). Next, to check the impact of soil type in tunnel formation as well as to see the ecological role of dung beetle in nutrient cycling, the soil nutrient analysis was done for all soil types and two groups viz., I: (control): Soil + dung beetles; and II: (experimental): soil + dung beetles+ dung were maintained. A total of eight soil samples were collected on 30th day, oven dried and homogenized, then, the nutrients, organic carbon and organic matter were analyzed following Maiti (2003). Statistical analysis was done using the Graphpad Prism software, version 8.4. Two-way ANOVA was used to compare groups followed by multiple comparison test to test the significant differences ($p \leq 0.05$).

RESULTS AND DISCUSSION

Identification of the soil was done based on the colour and was identified as yellow, red, black, and brown soil. Collected *O. taurus* showed unique characters and distinct sexual dimorphism, where males possessed a pair of horns while its females encompassed a broad, hardened plate like structure on their head (Fig. 1A). Both male and female clearly depicted teeth like structures on front tibia called as tibial teeth utilized in digging (Chandra and Gupta, 2013). Being a holometabolic insect, egg, larva, pupa and adult were observed and lasted 90-120 days (Fig. 1B). Brood development period and morphometrics were analysed (Table 1); development period was observed to be 12-16 weeks, and the size of the brood ball was also normal. Barkhouse and Ridsdill-Smith (1986) and Kaur et al. (2021) on *Onthophagus binoidis*, *O. coenobitis*, *O. fracticonis* and *O. vacca* observed that the soil type as well as the moisture content affects the larval development. Among the four types of the soil, the most preferred was yellow soil (sandy, 4% moisture) followed by red soil (sandy clay loam, 6% moisture) and brown soil (loamy sand, 3% moisture), while the least preferred was black soil (sandy loam soil, 11% moisture) (Table 3). Maximum brood balls

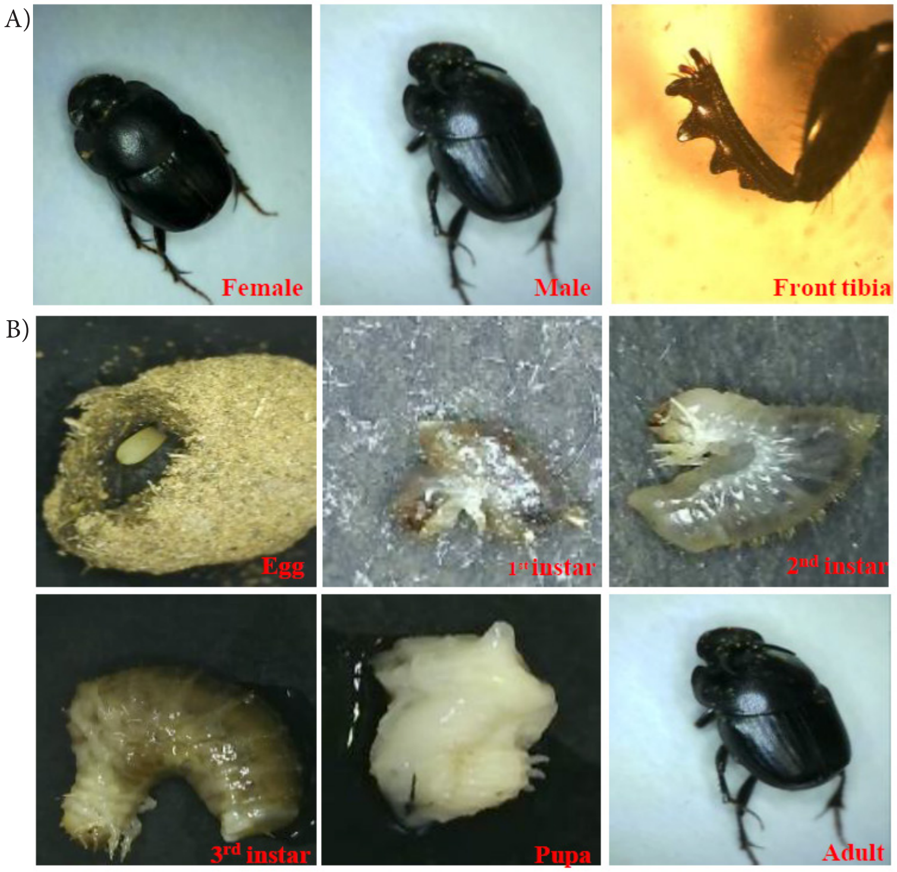

Fig. 1. Morphological characters of *O. taurus*. A. from right side- Female (no horns on head); Male (with horns on head); and front tibia with teeth (used for digging the soil and to make tunnels). B. Lifecycle of *O. taurus*- egg, larva-1st instar, 2nd instar, 3rd instar, pupa and adult (here, male)

Table 1. Developmental stages and brood morphometry of *O. taurus*

	Minimum days	Maximum days	Length (cm)	Width (cm)	Weight (g) (without brood ball)
Egg	2	4	0.1	0.1	0.01
1st Instar	2	3	0.4	0.3	0.014
2nd Instar	3	6	0.6	0.4	0.022
3rd Instar	4	8	0.9	0.5	0.030
Pupa	6	9	0.6	0.4	0.032
Adult male	80	90	1.2	0.9	0.056
Adult female	80	90	1.0	0.6	0.034

were observed in red soil (sandy clay loam- 22). *O. taurus* has ability to bury large amount of dung with a significant tunneling behaviour, and tunnel pattern in all soil types were analyzed (Table 2); and maximum area covered was in the yellow soil followed by brown soil, red and black soil (Fig. 2). Warren and Taylor (2014) observed that the tunneling is dependent on the compaction of soil, and has suggested that loam, silt loam, sand loamy to be the most suitable. Soil texture, water holding capacity, moisture content and soil porosity were analyzed (Table 3); texture analysis revealed that yellow soil was sandy type, red and black soil was sandy clay loam type where as brown soil was reported to be of loamy sand type. Water holding capacity was observed to be highest in sandy soil type, while moisture content was found to be maximum in sandy clay loam soil, with porosity being high in sandy and loamy sand soil.

Table 2. Dimensions of the tunnels formed by *O. taurus*

Soil type	NO	L	TD	W	D	Area	NB	Pattern
Yellow soil	15	10	7.8	0.9	3.8	7.06	2	Simple
Red soil	15	6.9	6.9	1.1	3.9	5.95	1	Simple
Black soil	8	3.5	5.4	1.9	3.5	5.22	1	Simple
Brown soil	13	4.9	15.5	1.7	3.8	6.53	1	Simple

NO = No. of burrow opening; L= length (cm); TD= Total depth (cm);
D= diameter area (cm2); NB= no. of branches

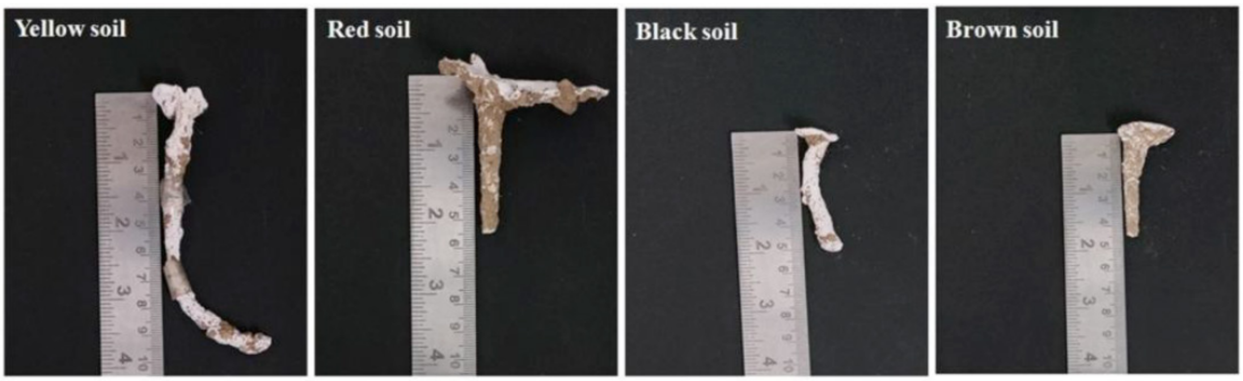

Fig. 2. Tunnel pattern in soil types after 30 days of introduction of *O. taurus*

Table 3. Texture, water holding capacity, moisture content and porosity of soil types

Soil type	Total depth (cm)	Sandy layer (cm)	Silt layer (cm)	Clay layer (cm)	% Sand	% Silt	% Clay	Texture	Water holding capacity (%)	Moisture content (%)	Porosity (%)
Yellow	11.6	11.4	-	0.2	95.27	-	1.72	Sand	11.11	4.65	100
Red	14	11	-	3	78.57	-	21.42	Sandy clay loam	19.04	6.43	92
Black	19	15	-	4	79	-	21	Sandy clay loam	20.48	11.27	47
Brown	12.3	10.2	1.8	0.3	83	14.75	2.43	Loamy sand	17.6	2.99	100

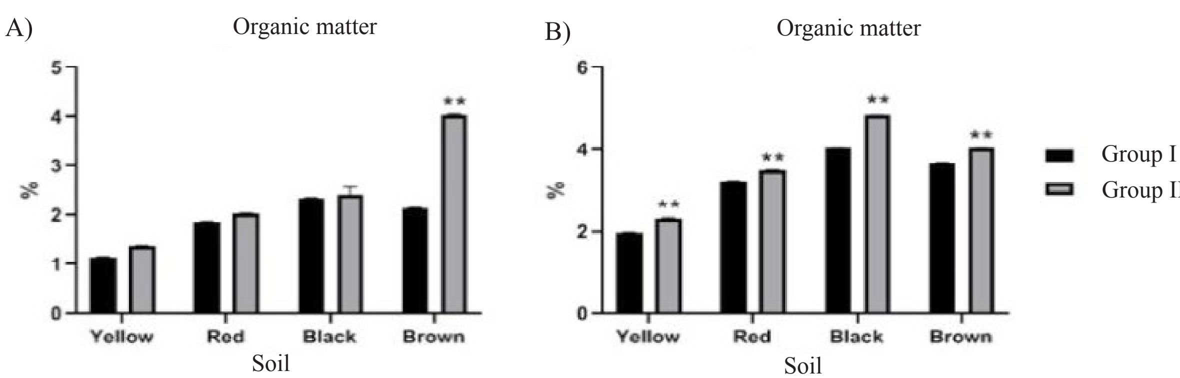

Fig. 3. Nutrient content of Soils- Group I (Control) and Group II (Experimental) after 30 days of release of *O. taurus* A. Nitrogen; B. Phosphorus; C. Calcium; D. Sodium; E. Potassium; F. Sulphur. A time dependent significant increase was observed in Group II suggesting the *O. taurus* activity- $p<0.01$**, $p<0.05$*

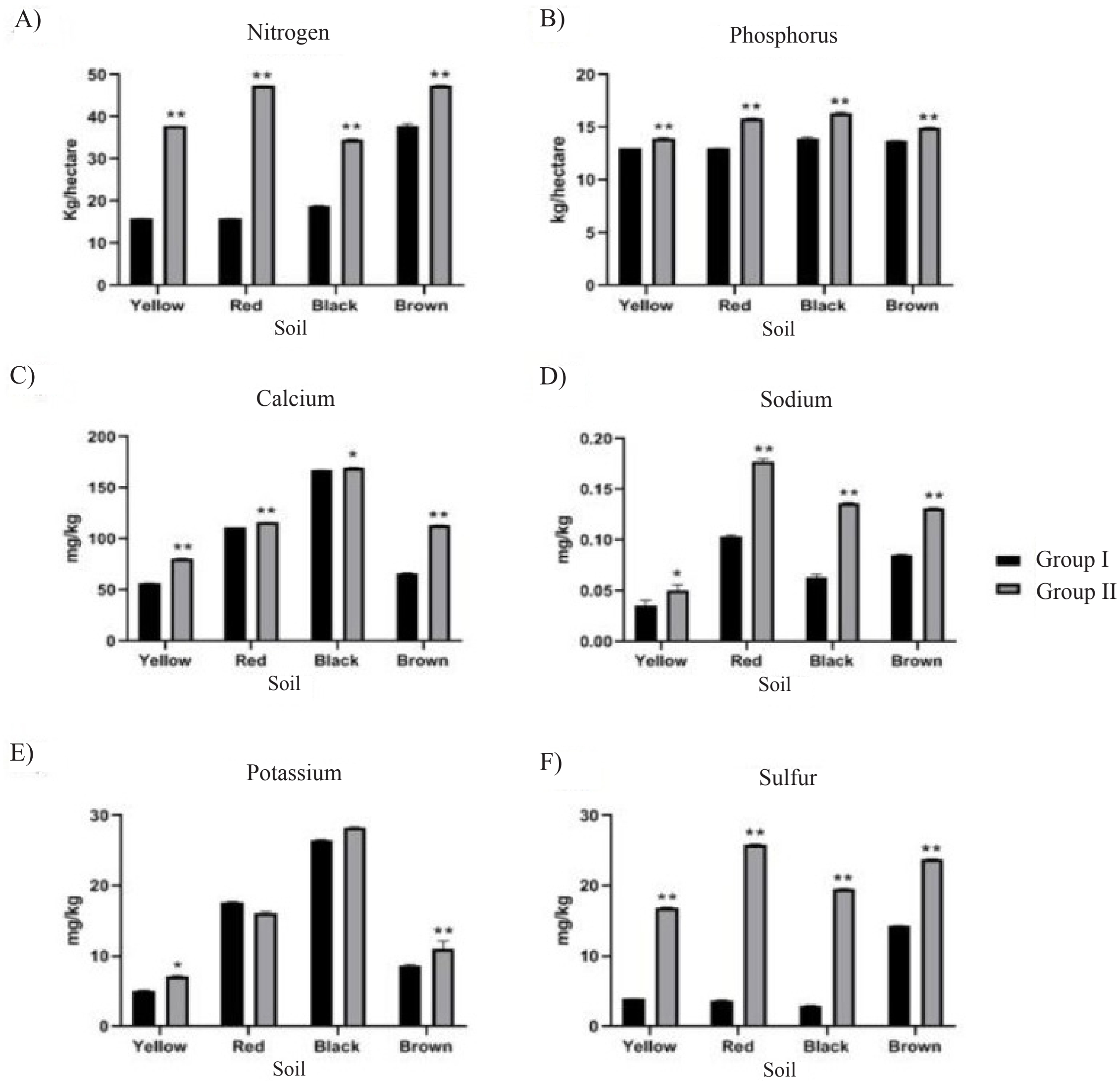

Fig. 4. A. Organic carbon, B. Organic matter- Group I (control), Group II (experimental) after 30 days of release of *O. taurus*- significant increase in the organic matter was observed after 30 days- p<0.01**, p<0.05*

Dung beetles carry out dung relocation and tunnelling activities by which it enhances soil nutrients (Bertone et al., 2006). In the present study, increase in N, K, P, Ca, Na and S as well as organic carbon and organic matter was observed in all the soil types after 30 days of release of beetles (Fig. 3, 4). Brood ball production inhibits ammonia volatilization, improving soil fertility by facilitating nitrogen absorption by plants (Maldonado et al., 2019). In addition, by making tunnels, dung beetles also help to reduce soil compaction and increase soil aeration, facilitating nitrogen mineralization (Manning et al., 2016; Xu et al., 2020; Stanbrook et al., 2021). An increase in the all the nutrients was observed in Group II in all the 4 soil types; however, N levels were found to be highest in sandy clay loam and loamy sand soilconfirming the affirmative role of the dung beetles in nutrient cycling (Zhao et al., 2008; Kronzucker, et al., 2013; Menéndez et al., 2016; Badenhorst et al., 2018; Kandil, 2019; Salomão et al., 2022). Thus, *O. taurus* appears to have an important role in nutrient cycling, and their relative importance also depends on the soil type. Their dung relocation and burrowing activities complementarily contribute to maintain soil fertility.

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AUTHOR CONTRIBUTION STATEMENT

NP and PP conceived and designed research. HS and NP carried out field visits and conducted experiments.

PS contributed gadget and analytical tool. HS and NP analyzed data. HS and NP wrote the manuscript. NP and PP revised the manuscript. All Authors read and approved the manuscript.

CONFLICT OF INTEREST/ COMPETING INTEREST

Authors have no competing interest.

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