STUDIES ON THE AMOUNTS OF DUNG BURIED AND SOIL EXCAVATED BY CERTAIN COPRINI (SCARABAEIDAE)

by

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INTRODUCTION

The agencies of nature involved in effecting soil manipulation, soil interchange, and fertilization are varied and numerous. A great deal has been written on the formation of vegetable mould and humus upon the earth's surface by the activities of various animals, particularly earthworms. The chemical processes involved in the decomposition of rocks, as well as the mechanical agitation of soil by plants and animals have also been investigated. It appears that the surface of the earth has been rendered

more capable of supporting plant growth through the burrowing action of rodents, worms and insects. The opening and agitation of the soil and incorporation of organic matter by these animals undoubtedly has resulted in a beneficial effect upon the earth's crust. The fact that insects play an important role in these operations has not been investigated in sufficient detail. Due to the enormous numbers of insect species, a large percentage of which invade the soil at some period of their life history, it is evident that the soil is influenced in many ways by their activities.

It is the object of these investigations to review briefly the literature on insects as soil builders and present some definite data obtained in studies of soil insects. These data are concerned with the amounts and kinds of organic material deposited in the earth, amounts of soil excavated and some burrowing habits of a few of the subterranean insects studied, with particular reference to certain dung beetles belonging to the tribe Coprini.

REVIEW OF LITERATURE

A review of the literature reveals chiefly the following points:

1. A dearth of definite quantitative work on the incorporation of organic materials into the soil by insects.

2. A difference of opinion regarding the value of insects as soil builders.

3. Many investigations on the insect population of the soil.

4. And a number of observations on ants as geologic agents.

Mention is made here of some of the more important papers and a brief summary of each.

Morris (1920) found in a permanent pasture in Cheshire an actual census of 3,586,088 insects to the acre. Later (1922) he reported 2,474,745 insects to the acre at Hertfordshire, on land that had not been manured or fertilized in any way for a period of 81 years. On a similar piece of land on which barnyard manure had been applied annually for 77 years, an average of 7,727,265 insects to the acre was determined. Again in 1927 he reports on the numbers of invertebrates and insects in soil on six plots which had been fertilized with different materials. Artificial manures had little or no effect on the soil fauna, while the effect of dung in increasing the numbers and species was considerable. McAtee (1907) made a census of the animal life in four square feet of soil to the depth a bird could scratch and estimated that there were 1,216,880 animals, principally insects, in an acre of woodland and 13,654,710 in meadow land. Felt (1928) states in regard

to solitary bees in lawns that calculations based on a photographed area of 300 square inches, indicate 376,362 holes to an acre.

McColloch and Hayes (1922) point out a reciprocal relationship existing between soil and insects. McColloch (1926) shows some ways in which insects cause deleterious effects upon the soil. These are chiefly excessive burrowing, detrimental effect on vegetation, especially lawns, by mounds thrown up by insects and injury to soil through the use of soil insecticides in an effort to control subterranean forms. Morris (1922) in a chemical analysis to show the nitrogen content of the various groups of soil invertebrates found that they furnished 16.2 pounds of nitrogen to the acre on a manured plot and 7.5 pounds on unmanured land. He concludes that although the bodies of invertebrate fauna contain an appreciable amount of nitrogen, there can scarcely be any loss or gain of nitrogen due to them. Cameron (1925) states that it is unlikely that soil insects contribute to fertility although their habit of burrowing may aid in soil areation. Shaw (1930) gives the following formula as an expression of those prime factors that control the trend of soil formation and development: $S = M (C - V)^T - D$, in which S = soil; M = parent material; C = climate; V = vegetation; T = time; and D = erosion or deposition. It will be noticed that

animals are not included. Taylor (1930) moves to amend Shaw's formula to read as follows: $S = M(C - V - A)^T - D$, the letters having the same meaning as above, with the addition of A, referring to animal life.

Juritz (1920) made an analysis of the droppings of Antheraea cytherea and compared it with horse, cow and barnyard manure. He found that caterpillar droppings contained a relatively high percentage of potash and compared favorably with the other manures in their contents of nitrogen, lime and phosphoric acid.

Branner (1900) states that in tropical regions ants and termites are vastly more important as geologic agents than earthworms of temperate regions. He further states that mounds of ants are from 15 to 30 meters long, 3 to 6 meters across, from one-third to one meter high, and contain tons of earth. Shaler (1891) calculates that ants in certain fields in Massachusetts transfer annually sufficient material from the subsoil to cover the surface to a depth of one-half centimeter. He explains the freedom of pebbles on certain sandy soils of New England, resting upon subsoil containing pebbles, as due to the upward transportation of soil by ants. McCook (1877) states that in the mountains of Pennsylvania ants build large mounds commonly measuring 10-12 feet in circumference and two and one-half to three feet high. There may be 29 to 59 hills per acre.

In a radio talk given in the spring of 1930, Dr. Frank Lutz stated that insects are more effective than earthworms as soil-makers. He attributed this to the greater distribution and numbers of insects and that insects carry materials rich in nitrogenous plant food beneath the surface of the soil.

In personal correspondence with Dr. Lutz, he states that to his knowledge there has been no adequate study on the amounts of soil turned over and organic materials deposited in the soil by insects.

METHODS

The present investigations were begun in the fall of 1929 in an attempt to determine the amounts of soil brought to the surface and amounts and kinds of organic matter that were deposited in the soil by insects in the vicinity of Manhattan, Kansas. This work included field and insectary studies to determine the burrowing habits of a few insects. Trips were made to pastures and fields for observation and excavation of these underground insects twice a week when the weather permitted. These studies were continued during 1930, beginning the middle of April and ending in November, a period of approximately seven months. The types of pastures investigated were the highland, lowland, and sandy areas which supported various kinds of

vegetation including: native prairie grass, blue grass, Sudan, sweet clover, and a pasture having a mixture of brome and orchard grasses.

When a burrow was found, usually indicated by a mound of soil, its diameter, length and depth were recorded together with a diagram of the passage-way. From the dimensions obtained the cubic contents of a few of the burrows were calculated. The soil, manure, other organic material, and insect responsible for the burrow were collected. A period of six weeks was allowed for air-drying the soil and manure before they were weighed. An effort was made to secure data on at least 15 representative burrows for each insect studied.

The usual procedure was first to drop a few grains of calcium cyanide into the burrow to kill the inhabitant, although this was not resorted to with any of the dung beetles. A straw or wire was then inserted to determine the general direction of the burrow and also serve as a guide in the process of excavation. A hole was then dug with a spade a few inches from the mouth of the burrow and thin layers were carved off until the burrow was reached. If care was taken to dig the hole wide and deep enough so as to extend beyong the extremity of the burrow, a representative longitudinal section was usually obtained. Difficulties were often encountered because of the winding and

twisting path of some of the tunnels. Plaster of Paris casts were made of a few of the tunnels studied in order to get an exact replica of the shape of the burrow.

Soil was dug from under a number of old cattle droppings and examined for dung beetle larvae which were located in small balls of manure. These were reared in the cave at the field insectary and the beetles determined by a specialist. Several dung beetles were placed in boxes containing soil and kept at the field insectary for a study of their burrowing habits. An attempt was also made to determine the beetle population in seven one-tenth acre areas.

PRESENTATION AND DISCUSSION OF DATA

Besides various ecological notes, numerical data were obtained on 90 burrows. Of this number, 70 belonged to species of the dung beetle group. The remainder of the burrows studied were made by wild bees, tiger beetles and crickets. The number of each species and group studied are as follows:

Pinotus carolinus	24
Copris tullius	25
Phanaeus spp.	21
Wild bees	4
Tiger beetles	7
Field crickets	9

General Discussion of the Dung Beetles

During the course of this work, particular attention was given to the dung beetles belonging to the tribe Coprini. They present an interesting study since they dig burrows and transfer manure into the cavities which they have excavated. The differences in burrowing habits and methods of depositing manure below the ground by the various species are also of interest.

It is the opinion of the writer that several species of dung beetles may have worked in the dung of the great herds of buffalo that once roamed the western plains, although no evidence was found in the literature to confirm this supposition. This opinion is based upon the fact that Thomas Say in 1823 published a report describing coleopterous insects collected in an expedition to the Rocky Mountains in which he mentioned many dung beetles. Leconte in 1859 published a list of Kansas Coleoptera in which are included several species of dung beetles, among them being Phanaeus carnifex and Onthophagus hecate. It would at least appear that some of the dung beetles are native of Kansas. When one considers the meager and slow mode of transportation prior to 1859, it seems improbable that these beetles were imported into this region.

In this study, it was found that dung beetles were present in every pasture where cattle grazed. The beetles encountered belong to the tribe Coprini, representing four genera and including six species; namely, Pinotus carolinus (1), Copris tullius Oliv., Phanaeus carnifex L., P. difformis Lec., Onthophagus pennsylvanicus Har., and O. hecate Panz. These were present in the native highland pastures north of Manhattan as well as in the lowland pastures along Wildcat Creek. Activity was observed in the city of Manhattan in a half acre plot on which one cow was pastured. Besides the native grass pastures the beetles were observed in blue grass, sweet clover, Sudan, and a mixture of brome and orchard grasses.

Their burrowing was not confined to grass areas inasmuch as activity was noted on bare spots, such as a road running through a pasture a cattle lane, and the stamping ground of cattle. Burrows have also been excavated and observed in underbrush, along creeks, ravines and on rocky ledges where cattle grazed. It can be stated that the dung beetles were located in every environment where cattle grazed, irrespective of the type of vegetation and soil. In pastures where both cattle and horses grazed, the horse droppings were rarely utilized. Further studies would be necessary to determine why cattle dung was preferred.

May and the first part of June were the months in which occurred the greatest burrowing activity of the dung beetles. This was especially true in the College nurse cow pasture which was under close observation during the period of study. From the middle of June to the middle of August there was a great decrease in the amount of burrowing. After the rains in August an increase in the amount of burrowing was observed. The period of depression in burrowing may have been due to the extremely hot and dry weather prevailing at that time. Nearly every day temperatures of over 100° F. were recorded, and much of the time 105° to 110° F. were registered.

A detailed study was made of each of the species concerned in these investigations and an individual record is herewith submitted.

Pinotus carolinus (L.)

This is a large black beetle measuring about 26 millimeters in length and about 17 millimeters in width across the abdomen. The thorax, as viewed from the front rises vertically from the clypeus for about 5 millimeters which makes the former very blunt, apparently well adapted for pushing soil. The clypeus which protrudes forward is broadly convex on the upper surface and is used for rooting. A beetle was observed in the act of moving the soil near

the entrance of a burrow using the clypeus much as a hog uses its snout in rooting. The writer was unable to determine how the beetle digs but the loosened soil is pushed out of the burrow. This process was observed during this study and can readily be deduced upon examining the mounds of earth. The soil often clings together forming a cylinder and a number of these masses, one-half to two inches in length may be lying over the entrance to the burrow.

The first burrowing of Pinotus carolinus in the spring of 1930 was observed on May 3 in a blue grass pasture on which the College nurse cows were grazed. Previous to this date many trips had been made to nearby pastures but no burrows were discovered. Cattle had not been turned out on native prairie grass pastures at this early date. Fresh burrows could be located any time during spring, summer and fall. Table I does not show any burrows excavated in August but a summary of the observations recorded indicate that there was considerable activity during the latter part of the month. The last extensive burrowing was on October 5, and after this date only two fresh diggings in dung were observed, one on October 17 and the other on October 25. The period of dung burial lasted therefore approximately five and one-half months.

Table I shows the data that was obtained on each individual burrow, together with date and place collected. The column headed by the word "depth" means the point in the tunnel that was fartherest under the surface of the earth. The volume of manure could only be calculated in the three instances that are shown. From an examination of the table it will be seen that the lengths of the main tunnels do not vary a great deal except in one case where the length was 162 centimeters. The diameters of the burrows are uniform, as would be expected. The depths also are nearly alike except for a few extremes. A great deal of variation is evident in the weight of soil and manure, and cubic contents of the burrows. It will also be observed that some burrows are inhabited by two beetles. This characteristic is not confined to any particular season but is prevalent throughout the burrowing period as is shown in the table. Of the 21 spring, summer, and early fall burrows of this species, only eight or 38 per cent were inhabited by two beetles. It may be stated here that two beetles were often found in the burrows of three other species which were studied. It is interesting to note that with C. tullius and Phanaeus spp. 34.7 and 35.2 per cent respectively of the burrows were occupied by two beetles. From this it is seen that there is not a great deal of difference between the three species in this

Table I. Showing Data on the Spring, Summer, and Early Fall Burrows of *Pinotus carolinus*.

Burrow No.	Date	Location	Dimensions of Burrows cm.				Weight of soil in grams	Cubic contents of burrows, cc.	Weight of manure in grams	Volume of manure in cc.	Number of beetles in burrow
			Length of main tunnel	Length of branch	Diameter	Depth					
62	5- 3-30	Nurse cow pasture	30	6	2.6	18	96.4	191.1	16.1		1
63	5- 9-30	" "	45	ruined	2.2	17	109.4	171.0	ruined		1
79	5- 9-30	" "	15	5	2.5	11	None collected	98.0	6.2		1
80	5- 9-30	" "	25	7	3.0	15	120.1	226.1	17.3		1
81	5- 9-30	" "	45	23	3.2	17	302.1	546.8	51.6	184.0	2
82	5-15-30	" "	26	20	2.7	10	182.0	262.9	37.1		2
83	5-15-30	" "	29	4	3.0	14	182.9	233.2	11.1		1
84	5-15-30	" "	33	10	3.0	16	186.2	303.9	26.9		1
85	5-25-30	" "	57	ruined	2.5	12	191.5	279.3	28.8		1
86	5-25-30	" "	30	4	2.6	10	None collected	180.5	None collected		2
87	5-25-30	" "	60	38	2.7	27	70.8	560.2	62.2		2
90	5-27-30	" "	40	12	2.6	22	123.5	276.0	64.3		1
91	5-27-30	" "	50	40	2.7	32	385.3	514.4	130.5	229.0	2
92	5-27-30	" "	21	38	2.7	22	229.2	337.3	116.8		1
97	6- 3-30	" "	11	31	2.8	10	None collected	258.5	63.5		1
102	6- 8-30	Wildcat	47	ruined	2.8	21	309.3	289.3	14.0		2
107	6- 8-30	Wildcat	162	26	2.7	55	815.9	1074.7	66.2		2
108	7- 8-30	Rock Quarry pasture	Not recorded				1220.9*		None collected		1
118	9- 7-30	W.A.H.Pasture	35	33	2.6	36	184.9	350.3	19.5	31.8	1
120	9-17-30	Rock Quarry pasture	32	11	2.7	23	171.2	245.8	21.5		1
123	9-17-30	" "	85	49	3.2	21	None collected	1077.6	119.4		2
Average			43.9	21	2.74	20.4	287.1	373.8	48.5		

* Not included in calculating average.

characteristic, and that approximately one-third of the burrows were inhabited by two beetles.

The burrows of this beetle were easily distinguished from those of other dung beetles by the larger mounds of soil, the larger particles of soil and greater diameter of tunnel. During the spring, summer, and early fall the burrows were invariably found at the margin of fresh cattle droppings. The main characteristic of these burrows was a branch leading away from the main tunnel at about five to 25 centimeters below the surface of the ground.

Table II shows that the branch varied in length from 4 to 40 centimeters, while the average was 21 centimeters. It was shorter than the main tunnel in nearly every burrow. Manure was stored in the branch in every burrow that was excavated, but often a small amount was also found in the termination of the main passage-way (Plate II, fig. 5). How the dung was transported into the burrow by the beetle was not determined.

Table II. Characteristics of spring, summer, and early fall burrows of *P. carolinus*

	Dimensions of burrows, cm.				Weight of soil in grams	Cubic contents of burrow	Weight of manure grams
	Length of main tunnel	Length of branch	Diameter	Depth			
Minimum:	11	4	2.2	10	70.8	98.0	6.2
Maximum:	162	40	3.2	55	1220.9	1077.6	130.5
Average:	43.9	21.0	2.74	20.4	287.1	373.8	48.5

The main tunnel varied in length from 15 to 162 centimeters with an average of 43.9 centimeters (Table II). Occasionally it would take a course opposite to the manure tunnel and often it was parallel to it (Plate I, figs. 1 and 2). Since 162 centimeters is equivalent to a little more than five feet it may be seen that this beetle is capable of excavating large amounts of soil. Both the main tunnel and branch were characterized by twisting and abrupt turns, smooth walls, circular shafts, and nearly identical diameters.

Beginning on October 5, a great many burrows were observed 18 inches to three or four yards away from dung. These differed from the burrows at the edge of cattle droppings in that they went straight down without any branch or pocket, had no stored manure and the tunnels were packed with soil for the greater part of their length. A single beetle was found in the termination of the shaft.

Table III. Showing the Dimensions of the Late Fall Burrows of P. carolinus

Burrow number	Location	Date	Dimensions of burrows, cm. Length of burrow	Depth	Diameter
127	Rock Quarry Pasture	10- 5-30	49	49	2.3
128	" " "	10-25-30	65	72	2.5
136	" " "	12-11-30	48	50	3.0
Average			54	57	2.6

The average depth of these burrows was 57 centimeters, over twice the depth of the spring, summer, and early fall burrows, which were 20.4 centimeters. Inasmuch as a previously marked burrow of this type was excavated in December and a live beetle found therein, it is the belief of the writer that this may be the overwintering quarters of this species.

The amounts of dung stored by these beetles was found to vary from 6.2 to 130.5 grams, while the average was 48.5 grams (Table II). These weights are rather small but it must be remembered that dry manure is comparatively light, a few grams express a volume greater than would naturally be expected. In only a few cases was the volume of manure determined, and it is seen from Table I that the 130.5 grams, which was the maximum amount found, had a volume of 229 cubic centimeters.

Since dung beetles and their larvae are known to feed on dung, the question arose as to whether or not all the manure was consumed. By excavating some burrows in December which had previously been marked, it was found that not all of the dung had been consumed. As a matter of fact a considerable amount remained, all of it in a state of decay. This was true with all the dung beetles studied. Incidentally, it may be stated that in the partly decomposed manure in one of the burrows were found many dipterous maggots,

which on being reared to adults were determined as belonging to the family Mycetophilidae.

The portion of the manure which was consumed by the beetles would not necessarily be lost as far as a fertilizer is concerned, because the beetle feces would no doubt contain materials that would be of value to the earth. Beetle feces were found in abundance in the burrows. It was mentioned in the review of literature that Juritz (1920) found caterpillar droppings to compare favorably with other manures in containing the necessary soil elements.

The amount of soil brought to the surface by P. carolinus was enormous in comparison with that of the other insects studied. Table II shows that the smallest amount was 70.8 grams, and the greatest 1220.9 grams, while the average for each burrow was 287.1 grams. The cubic contents varied from 98.0 to 1077.6 cubic centimeters with an average of 373.8 cubic centimeters. The great variation in the amount of soil excavated and cubic contents of the burrow as well as dung deposited is difficult to explain. Possibly the burrows were not completed in all cases when the data was taken. It is difficult to recognize with certainty when a burrow is completed.

It might be stated that in the native highland pastures the mounds of soil were red in color, this being due to the fact that the highly colored subsoil is close to the surface.

In this manner large amounts of subsoil would be exposed. The amount of soil collected at each burrow does not represent all the soil that was dug out of the tunnel because the first part of the burrow was usually closed and some of the soil in the mound may have been blown away or otherwise dispersed. Neither is the estimation of the cubic contents of each burrow entirely correct. However, the weights of the excavated soil indicate that much subsoil was brought to the surface and the cubic contents of the burrows show that large underground cavities were dug.

The exact length of time necessary for P. carolinus to complete a burrow was not determined. However, observations after rains indicated that it may have been completed in about two days or less.

It will be noticed that where two beetles were present in a burrow, its dimensions were usually greater than where only one occupied the home. Likewise more soil was transported to the surface and more manure deposited. A comparison of the averages of one-beetle burrows and two-beetle burrows is shown in Table IV. An examination of the table shows that in every particular except diameter the two-beetle burrows exceed the one-beetle burrows. The average length of the main tunnels of the burrows in which one adult of P. carolinus was present was found to be 31.8 centimeters while those in which two beetles, belonging to that species,

were found, averaged 63.1 centimeters. In this instance the ratio of the length of the main tunnel of the one-beetle burrows to the two-beetle burrows was 1:2. A similar ratio has been calculated for the length of branch, depth of burrow, the weight of soil excavated, manure deposited, and cubic contents of burrow. The ratios indicate that two beetles accomplish approximately twice as much as one, since the average of these ratios is 1:1.88 with a range of 1:1.3 for the minimum and 1:2.2 for the maximum.

Table IV. Showing a Comparison of One- and Two-Beetle Burrows of P. carolinus.

		Dimensions of burrows, cm.			Weight of soil, grams	Cubic contents of manure	Weight of manure, grams
	No.	Diameter	Length of main tunnel	Length of branch	Depth			
One-beetle	13	2.68	31.8	15.7	18.0	159.5	247.5	35.6
Two-beetle	8	2.83	63.1	28.5	24.1	344.2	563.3	68.7
Ratio			1:2	1:1.8	1:1.3	1:2.1	1:2.2	1:1.9

In the Rock Quarry pasture, on September 17, two one-tenth acre plots were measured off in different parts of the field, and a count of the fresh mounds of P. carolinus was taken. There were found to be 15 mounds on one and 25 on the other. At this rate of distribution there would be an average of 200 burrows to the acre. Observations in the spring indicated that the rate of distribution was as great as this in some areas and much less in others.

Using 48.5 grams as the average amoung to manure deposited in each burrow and 287.1 grams the amount of soil excavated, a total of 9.7 kilograms or 21 pounds of air-dried dung would be buried by 200 beetles in an acre of ground and 57 kilograms or 126 pounds of soil excavated. This is not a large amount but when it is taken into consideration that dung burial takes place continuously during the spring, summer, and early fall, and that the process is repeated yearly, it appears that a considerable quantity of manure would be deposited in the earth. Since there are many species engaged in the same operations it is believed that dung beetles can be recognized as a factor in soil fertilization, and soil interchange.

Copris tullius Oliv.

C. tullius is a black beetle considerably smaller than P. carolinus but resembling it to a certain extent. It measures about 14 millimeters in length and about 8 millimeters in width across the abdomen. Its habits of pushing out the soil in cylinder-like masses and burrowing at the edge of cattle droppings are similar to those of P. carolinus, but the structure of the burrow is different in that it has no branch and the manure is stored in the form of a ball at the end of the burrow (Plate II, figure 4).

Table V gives the data on each burrow that was excavated together with date and place of collection. The cubic contents of the burrows were not calculated. The cavity in which the manure was stored was usually egg-shaped. Column 8 in Table V gives the diameters and lengths of the cavities studied.

Table V shows that the burrows excavated in August and October of 1929 are less in length, depth, and amount of stored manure than those excavated in 1930. No satisfactory explanation can be given concerning this. It will also be seen that burrows were excavated in four different pastures. The tunnels in most cases were fairly uniform in length, 4 and 32 centimeters being the extremes. Also the depths were fairly constant except for a few shallow burrows. In diameter of burrows one would not expect a great difference and such is the case, since the range between maximum and minimum is only 0.4 centimeter. The measurements of the manure cavities are approximate and the variation is not very great. The weight of soil excavated and manure deposited shows considerable variation but, as was pointed out above, this fact is difficult to explain.

The first activity of these beetles in 1930 was observed on May 1 in the blue grass pasture mentioned above. Evidence of considerable activity at this time was shown by a count of 22 burrows in a distance of 20 linear feet. Dur-

Table V. Showing Data on Spring, Summer, and Early Fall Burrows of C. tullius.

Burrow No.	Date	Location	Dimensions of Burrows in Centimeters: Length	Diameter	Depth	Manure cavity, approximately	Weight of soil in grams	Weight of manure in cc.	Number of beetles in burrow
15	8-27-29	Pasture, N. Hills	8	1.0	5.5	2 x 3	5.8	1.3	1
20	8-29-29	" " "	6	1.2	5.5	1.8 x 3.5	None collected	1.4	1
21	8-29-29	" " "	6	1.2	5.0	1.4 x 2.5	" "	0.9	1
22	8-29-29	" " "	7	1.2	5.0	2 x 2.8	" "	1.9	1
29	10-6-29	Wildcat	4	0.9	2.0	1.5 x 1.5	" "	1.6	1
32	10- 6-29	"	11	1.0	9.0	2 x 2	" "	0.7	1
33	10- 6-29	"	12	1.1	10.0	1.8 x 2	" "	1.1	1
59	5- 1-30	Nurse cow pasture	16	1.3	15.0	3.5 x 3.5	73.6	5.1	2
60	5- 1-30	" " "	14	1.2	12.0	3.0 x 3.5	51.5	10.8	2
69	5- 4-30	" " "	16	1.2	13.0	3.0 x 5.0	65.3	16.4	1
71	5- 4-30	" " "	12	1.2	10.0	4.0 x 5.0	62.6	18.1	2
89	5-25-30	" " "	18	1.1	10.0	Not recorded	None collected		1
93	5-30-30	Pasture, N. Hills	10	1.0	8.0	4.0 x 5.0	None collected	10.8	2
95	5-30-30	" " "	17	1.0	10.0	4.0 x 5.5	" "	12.7	1
96	5-30-30	" " "	18	1.1	9.0	3.0 x 5.0	" "	9.5	2
99	6- 8-30	Wildcat	16	1.2	10.0	2.0 x 2.2	12.9	5.6	1
104	6- 8-30	"	15	1.1	8.0	Not recorded	None collected	8.2	1
106	6-23-30	Nurse cow pasture	10	1.0	8.5	3.0 x 4.0	15.8	6.9	1
121	9-17-30	Rock quarry pasture	9	1.0	7.5	Not recorded	23.5	5.5	1
129	10-25-30	" " "	32	1.2	19.0	4.0 x 4.5	28.9	12.8	2
130	10-25-30	" " "	19	1.1	15.0	Not recorded	30.7	10.2	2
131	10-25-30	" " "	20	1.1	15.0	5.0 x 6.5	48.9	11.5	1
132	10-25-30	" " "	16	0.9	13.0	3.0 x 5.0	34.5	6.8	2
Average			13.5	1.1	9.78	2.8 x 3.79	37.8	7.26	

ing the extremely hot and dry weather of July and August scarcely any burrowing was done by C. tullius. In September and October they were working in fresh dung in great numbers. A census of a one-tenth acre plot taken on October 25 in the Rock Quarry pasture showed a count of 18 fresh mounds. This species continued to bury dung later in the fall than any of the other Coprini that were studied. The last fresh burrow was observed on November 3.

The mounds of soil made by C. tullius were not easily distinguished from those of Phanaeus spp. because they were often nearly the same size. When the burrow was opened and its diameter noted the occupant could be determined by the size of the tunnel, the smaller being that of C. tullius.

The chief characteristic of the home of these beetles is that the tunnel always terminated in an oblong or nearly circular cavity in which a neatly moulded ball of dung was stored, under which the beetles were usually located. This ball did not occupy the entire cavity inasmuch as a distance of about one-half centimeter separated it from the earthen wall. The tunnel usually entered the ground at a slight angle and continued with few or now turns (Plate I, fig. 3). The walls of the passage-way were smooth and circular.

On October 26 a number of burrows were found from one to five yards away from dung. They went vertically into the ground, did not have a cavity, and had no stored manure.

Table VI shows the data recorded on the fall burrows that were excavated. It will be noticed that the average depth of 22 centimeters is over twice that of the burrows made earlier in the year, which had an average depth of 9.7 centimeters.

Table VI. Showing Data on the Fall Burrows of C. tullius

Burrow number	Location	Date	Dimensions of burrows, cm. Length	Depth	Diameter
134	Wildcat	10-26-30	19	19	1.1
133	Wildcat	10-26-30	25	25	1.2
Average			22	22	1.15

Table VII gives the range and average of data secured on the burrows of C. tullius. An examination of column 6 shows that the amount of dung stored varied from 0.7 to 16.4 grams, with an average of 7.26 grams. Dung was stored in every burrow excavated. No larvae were found in any of the dung balls stored by these beetles. The minimum amount of soil excavated was 5.8 grams, the maximum 73.6 grams, while the average was 37.8 grams.

Table VII. Characteristics of the Spring, Summer, and Early Fall Burrows of C. tullius.

	Dimensions of Burrows, cms. Length of burrow	Depth	Diameter	Size of manure cavity, approx.	Weight of soil in grams	Weight of manure in grams
Minimum	4	2	0.9	1.8 x 2.0	5.8	0.7
Maximum	32	19	1.3	5.0 x 6.5	73.6	16.4
Average	13.5	9.78	1.1	2.8 x 3.79	37.8	7.26

The average length, depth, and diameter of the burrows were 13.5, 9.78 and 1.1 centimeters, respectively. These dimensions are considerably less than those of P. carolinus which are: length, 43.9 centimeters; depth, 21 centimeters; and diameter, 3.2 centimeters. The minimum amoung of soil excavated was 5.8 grams, the maximum 73.6 grams and average 37.8 grams.

With this beetle as with P. carolinus, more work was accomplished when two beetles were present in a burrow than when only one occupied the home. Table VIII gives a comparison of the average data of one-beetle burrows with that of two-beetle burrows. Only with the weight of manure is a 1:2 ratio evident. In the other columns except diameter a ratio very close to 1:1.5 is approximated. The average ratio of all the columns, except diameter, is 1.55 with a range of 1.33 for the minimum and 1.95 for the maximum. From this it will be seen that two beetles accomplish approximately one and one-half times as much as one beetle. Eight or 34.7 per cent of the burrows were occupied by two specimens.

Table VIII. Showing a Comparison of One- and Two-Beetle Burrow of C. tullius

	No.	Diameter	Length	Depth	cavity	Weight of soil, grams	Weight of manure, grams
One-beetle	15	1.08	11.6	8.26	2.45 x 3.37	28.7	5.37
Two-beetles	8	1.12	17.1	12.6	3.5 x 4.5	46.9	10.5
Ratio		1:1.47	1:1.52	1:1.42-1:1.33		1:1.63	1:1.95

Phanaeus spp.

Two species of Phanaeus were found in this study, and the data in Table IX does not distinguish between them. The beetles are much alike in appearance and it seems that the differences in burrowing habits are not marked.

Table IX gives the record of burrows excavated. It will be noticed that only five of the seventeen burrows examined were branched so this does not appear to be a characteristic habit. The average length of the branches was 7.2 centimeters. The length of the main tunnels, depths and diameters of the burrows do not show much variation. The weights of the soil excavated have a wide range while the cubic contents of the burrows show a uniformity. The weights of the manure differ considerably. Six or 35.2 per

Table IX. Showing Data on Spring, Summer and Fall Burrows of Phanaeus spp.

Burrow No.	Date	Location	Dimensions of Burrows, cm.: Length of main tunnel	Length of branch	Depth	Diameter	Weight of soil in grams	Cubic contents of burrows, cc.	Weight of manure in grams	Number of beetles in burrow
54	5- 1-30	Nurse cow pasture	20	None	4	1.5	32.1	35.3	8.5	2
55	5- 1-30	" " "	3	"	2	1.4	Burrow not completed			1
56	5- 1-30	" " "	11	"	3	1.3	None collected	13.2	2.6	2
57	5-1 -30	" " "	24	"	7	1.8	None collected	61.1	None collected	2
61	5- 3-30	" " "	9	8	5	1.9	149.5	49.1	10.1	1
64	5- 3-30	" " "	14	None	4	1.6	None collected	28.1	None collected	1
65	5- 3-30	" " "	15	"	3	1.3	160.4	19.8	2.5	1
66	5- 3-30	" " "	16	"	7	1.8	None collected	40.7	13.3	1
68	5- 4-30	" " "	20	"	8	1.7	152.2	45.2	5.5	2
70	5- 4-30	" " "	15	8	9	1.5	102.2	40.5	30.2	2
72	5- 4-30	" " "	18	6	8	1.5	None collected	42.1	21.1	2
78	5- 9-30	" " "	11	None	7	1.8	31.5	28.0	6.5	1
88	5-25-30	" " "	17	10	10	1.5	None collected	65.1	5.2	1
115	9- 7-30	W.A. H. Pasture	11	None	7	1.4	"	16.9	10.6	1
117	9- 7-30	W.A. H. Pasture	16	"	8	1.5	"	28.2	4.3	1
119	9- 7-30	Wildcat	12	"	6	1.4	"	18.4	6.6	1
122	9-17-30	Rock Quarry Pasture	12	4	7	1.3	26.5	21.1	7.8	1
Average			14.3	7.2	6.1	1.54	93.4	34.5	9.62	

cent of the burrows were occupied by two beetles.

Dung was stored in the termination of every burrow that was excavated (Plate II, figure 6). The path of the tunnels was tortuous but regular throughout (Plate I, figure 4).

The first burrowing was observed May 1 in a blue grass pasture. The beetles were very abundant throughout May. In the latter part of August and in September considerable burrowing activity was noted. On October 17, the last burrow in dung was recorded.

Table X shows the data on the fall burrows. The depths of the tunnels were greater than in the burrows made earlier in the year. This fact was pointed out with reference to the other two species discussed above. Burrow number 135 was marked in November and excavated on December 11. A single adult beetle was found at the extremity and since the specimen was alive, it is believed as pointed out above, that this type of burrow may be the over-wintering quarters.

Table X. Record of Fall Burrows of Phanaeus spp.

Burrow No.		Date	Dimensions of burrows, cm. Length	Depth	Diameter
124	Nurse Cow Pasture	10- 5-30	45	45	1.6
125	Rock Quarry Pasture	10- 5-30	36	36	1.5
126	" " "	10- 5-30	25	25	1.4
135	" " "	12-11-30	22	22	1.4
Average			32	32	1.47

In Table XI the weight of the soil was not averaged, because so few mounds were collected. However, it may be seen that the average length, depth, and diameter of the burrows were 14.3, 6.1 and 1.54 centimeters, respectively. The cubic contents varied from 13.2 to 65.1 cubic centimeters, with an average of 34.5 cubic centimeters. The weight of the manure deposited ranged from 2.5 to 30.2 grams, while the average was 9.62 grams.

Table XI. Characteristics of Spring, Summer and Early Fall Burrows of Phanaeus spp.

	Dimensions of burrows: Length of burrow	Depth	Diameter	Cubic contents of burrow, centimeters	Weight of manure in grams
Minimum	3	2	1.3	13.2	2.5
Maximum	24	10	1.9	65.1	30.2
Average	14.3	6.1	1.54	34.5	9.62

A comparison was also made of the one-beetle and two-beetle burrows in order to determine if the same ratio held true for this species as for P. carolinus and Copris tullius. Table XII shows the record of these burrows. The weights of soil are not included in the table. In diameter and depth of burrow there is scarcely any difference between the two. The length and cubic contents of burrow and amount of manure deposited are greater in the two-beetle burrows. There is nearly a ratio of 1:2 in the weight of manure but an

average of the ratios is 1:1.51, which is similar to that of C. tullius, which had an average ratio of 1:1.55. Both of these ratios are less than the average ratio of P. carolinus which was 1:1.88.

Table XII. Showing Comparison of One- and Two-Beetle Burrows of Phanaeus spp.

		Dimensions of burrows, cc.		Cubic contents of burrow, cc.	Wt. of manure, gm.
	No.	Diameter	Length	Depth		
One-beetle	11	1.53	12.3	6.6	31.5	7.43
Two-beetle	6	1.55	18	6.5	39.5	13.6
Ratio			1:1.46	1:1	1:1.25	1:1.83

Table XIII shows a comparison of the averages of data of P. carolinus, C. tullius and Phanaeus spp. It will be noticed that P. carolinus constructs a larger burrow and buries more manure than either of the other species. There is very little difference in the length, depth and diameter of burrow and manure deposited in the soil, between C. tullius and Phanaeus spp. The table shows more soil was excavated by Phanaeus spp. than C. tullius but this may be due to the fact that so few mounds of Phanaeus spp. were collected.

Table XIII. Showing a Comparison of the Average Data of *P. carolinus*, *C. tullius* and *Phanaeus* spp.

	Dimensions of burrow, cm.				Wt. of soil, grams	Cubic contents of burrows	Weight of manure, grams
	Length of main tunnel	Length of branch	Depth	Diameter			
P. carolinus	43.9	21.0	20.4	2.74	287.1	373.8	48.5
C. tullius	13.5	None	9.78	1.1	37.8	Not calculated	7.26
Phanaeus spp.	14.3	7.3	6.1	1.54	93.4	34.5	9.62

Onthophagus hecate Panz. and *O. pennsylvanicus* Har.

In the latter part of June while examining soil under dried cow dung, a number of oblong manure pellets were found. They varied in depth from three to 17 centimeters and there was no indication of a tunnel leading from the pellet to the surface of the soil. Evidently these manure balls had been buried and the tunnel packed with soil sometime before. Possibly this took place in early spring since the droppings were dry but did not appear to have weathered over the winter. In each of the balls was a small humpbacked, white larva. The pellets were of two sizes, the larger ones having an average length of 17 millimeters while the diameter was 8.5 millimeters. The average length

and diameter of the small pellet was 9 and 5 millimeters, respectively.

A number of pellets, including both sizes, were placed in the cave of the field insectary and upon emergence it was determined that the small larvae were those of Onthophagus pennsylvanicus. The period of emergence was from July 19 to July 21. The large pellet contained larvae of O. hecate. Emergence took place between August 25 and September 5.

The pupal cases were black, nearly round, and were rather brittle. They had been formed from the manure in which the larvae lived. A considerable portion of the dung remained after the insect transformed from the larva to the pupal stage and would be of value to the soil. The average weight of the large pellet was 0.26 grams, and the weight of the small one was 0.11 grams.

Soil was examined under 43 droppings in three different pastures for these pellets. Table XIV shows a record of the diggings. The average number of pellets to a dropping includes both sizes, no distinction was made in the counting.

Table XIV. Record of the Diggings Under Partly Dry Cattle Dung

	Date	Number of droppings examined	Number of droppings infested	Percentage of droppings infested	Av. No. of pellets to dropping
Nurse Cow Pasture	6-26-30	16	11	68.7	11
W.A.H. Pasture	6-30-30	12	12	100	8
Wildcat	7- 1-30	3	2	66.6	17
W.A.H. Pasture	7- 7-30	12	10	83.3	9
Average				76.6	11.25

Pellets were found under 76.6 per cent of the droppings examined, and there was an average of 11.25 pellets under each infested dropping. From this it would appear that these two species infest a large percentage of droppings and that they bury an appreciable amount of dung.

Infestation on Definite Areas

A census of the dung beetles having freshly dug mounds of soil, was taken on two one-tenth acre plots in a blue grass pasture in May, and again in similar areas in the same pasture in June. Table XV shows the number of fresh droppings, percentage of infestation, and an estimation of the numbers of beetles to an acre. The June census showed

an average of 28 droppings, 45 per cent of which were infested, while in May there were 58 droppings and 40.5 per cent infestation. The percentage of infestation remained nearly the same in both months, notwithstanding the fact that the number of droppings differed.

The estimation of the numbers of beetles to an acre showed 120 in May and 235 in June. These figures represent the minimum number, since some droppings may have more than one burrow at its margin.

The data in Table XV represents only fresh mounds of soil. Rains nearly obliterated traces of old mounds, so the new burrows that were constantly being made were easily distinguished. Whether the constant burrowing was brought about by a beetle making more than one burrow, or by different generations of the species was not determined.

Table XV. Data on the Census of Dung Beetles in One-tenth Acre Plots

Plot	Date	No. of fresh droppings	No. of droppings infested by dung beetles	Percentage of droppings infested	Number of beetles to an acre
Plot A	5-4-30	39	15	38	150
Plot B	5-4-30	17	9	52	90
Average		28	12	45	120
Plot C	6-3-30	65	25	38	250
Plot D	6-3-30	51	22	43	220
Average		58	23.5	40.5	235

Tiger Beetles, Field Crickets and Wild Bees

While conducting these investigations, data was secured on burrows of a few miscellaneous insects other than dung beetles. These observations are recorded in Table XVI. The record of the quantity of soil excavated is not very complete.

Of the Tiger beetle burrows examined, it was found that the average diameter was 7 millimeters, while the length was 9.75 centimeters and depth 7 centimeters. All of these burrows entered the soil at an angle of about 35°. They were cylindrical with few or no turns. The removed soil was broken into fairly small granules and was stacked in a mound immediately outside the entrance.

The field crickets, belonging to the genus Nemobius, make a burrow that enters the earth at an angle of about 30°, continues for about an inch and then either goes down perpendicularly or makes a short turn or two before going down. The average measurements showed a diameter of 6.88 millimeters; length, 3.54 centimeters; and depth, 11.27 centimeters. These burrows are more or less irregular in diameter. They were fairly abundant and were found particularly in sandy loam soil.

Wild bees were found to dig burrows nearly straight down into the earth. The path of the tunnels was tortuous,

Table XVI. Record of the Burrows of Some Miscellaneous Insects

Burrow No.	Date	Place	Insect	Dimensions of Burrows: Diam. (mm.)	Length (cm.)	Depth (cm.)	Weight of soil (gms.)
28	10- 6-29	Wildcat	Tiger beetle	6	10	5	4.3
34	10- 7-29	Wildcat	Tiger beetle	8	9	8	7.3
38	10- 7-29	Wildcat	Tiger beetle	6	15	11	7.6
42	10- 7-29	Wildcat	Tiger beetle	7	10	7	6.9
43	10-13-29	Sand dune	Tiger beetle	8	8	6	None
44	10-13-29	Sand dune	Tiger beetle	7	7	5	None
45	10-13-29	Sand dune	Tiger beetle	7	10	7	None
			Average	7	9.75	7	
1	8-21-29	E.A.H. Pasture	Nemobius spp.	6	3.8	3	None
2	8-21-29	E.A.H. Pasture	Nemobius spp.	6	3.6	3	None
27	10- 6-29	Wildcat	Nemobius spp.	6	10.5	10.5	None
35	10- 7-29	Wildcat	Nemobius spp.	7	16	16	None
36	10- 7-29	Wildcat	Nemobius spp.	7	11	11	None
37	10- 7-29	Wildcat	Nemobius spp.	7	28	23	None
39	10- 7-29	Wildcat	Nemobius spp.	8	19	8	
40	10- 7-29	Wildcat	Nemobius spp.	7	14	12	
41	10- 7-29	Wildcat	Nemobius spp.	7	18	15	
			Average	6.7	13.54	11.27	
17	8-28-29	College Farm	Wild bee	14	4	4	None
18	8-28-29	College Farm	Wild bee	13	55	50.5	22.9
23	8-29-29	Pasture - hills	Wild bee	10	47	42	None
24	8-29-29	Pasture - hills	Andrenidae	6	27	27	None

the walls were very smooth and diameters regular throughout. In the case of an Andrenid burrow that was excavated two earthen nests were found in the tunnel; one was down 17 centimeters, contained 14 cells and weighed 1.6 grams; the other was at the end of the burrow, contained 4 cells and weighed 0.5 grams. They were composed of light clay soil which must have been brought in from the outside since the soil encircling the burrow for some distance was red sandy clay. This is a good example of how soils may become interchanged.

SUMMARY

1. In the vicinity of Manhattan, Kansas, it was found that dung beetles were located in every environment where cattle grazed.

2. Dung was buried from the first of May until early fall by Pinotus carolinus, Copris tullius and Phanaeus spp.

3. P. carolinus makes a burrow that has a branch leading away from the main tunnel. Cattle dung was stored in the branch and the quantity in each burrow varied from 6.2 to 130.5 grams with an average of 48.5 grams. The average amount of soil excavated from each burrow was 287.1 grams.

4. In the fall, these beetles constructed burrows which differed from the earlier burrows. Copris tullius and Phanaeus spp. also had a fall burrow which differed from the summer burrows. It is the belief of the writer that these burrows may be the over-wintering quarters of these species.

5. Where two beetles occupied the burrow, the amounts of manure stored and soil excavated were greater than where only one beetle was present. The percentage of burrows in which two beetles were present, together with the species, is as follows: P. carolinus, 38 per cent; C. tullius, 34.7 per cent.

6. A census of two one-tenth acre plots in September showed an average of 20 fresh burrows of P. carolinus on each plot. At this rate of distribution a total of 9.7 kilograms of manure was deposited and 57 kilograms of soil was excavated on an acre of ground.

7. Copris tullius excavates a burrow which terminates in an oblong cavity where a ball of manure is stored. The average amount of soil excavated and manure stored was 37.8 and 7.26 grams, respectively.

8. Phanaeus spp. store dung at the end of the burrow. The average weight of the soil and manure was 93.4 and 9.62 grams, respectively.

9. Under 76.6 per cent of dry droppings were found small manure pellets which were the larval home of Onthophagus hecate and O. pennsylvanicus. There was an average of 11.25 pellets under each infested dropping.

10. A census of the dung beetles having fresh mounds of soil on two one-tenth acre plots in May and in the same pasture again in June showed that the May census had an average of 28 fresh cattle droppings, 45 per cent of which were infested, while in June there were 58 droppings and 40.5 per cent infestation. The percentage of infestation was nearly the same in both cases, but the number of droppings differed.

ACKNOWLEDGMENTS

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EXPLANATION OF PLATES

PLATE I.

Diagram of Burrows

Diagrams of the burrows of *P. carolinus*, *C. tullius*, and *Phanaeus* spp., showing their comparative size. About one-third actual size.

PLATE I. DIAGRAM OF BURROWS

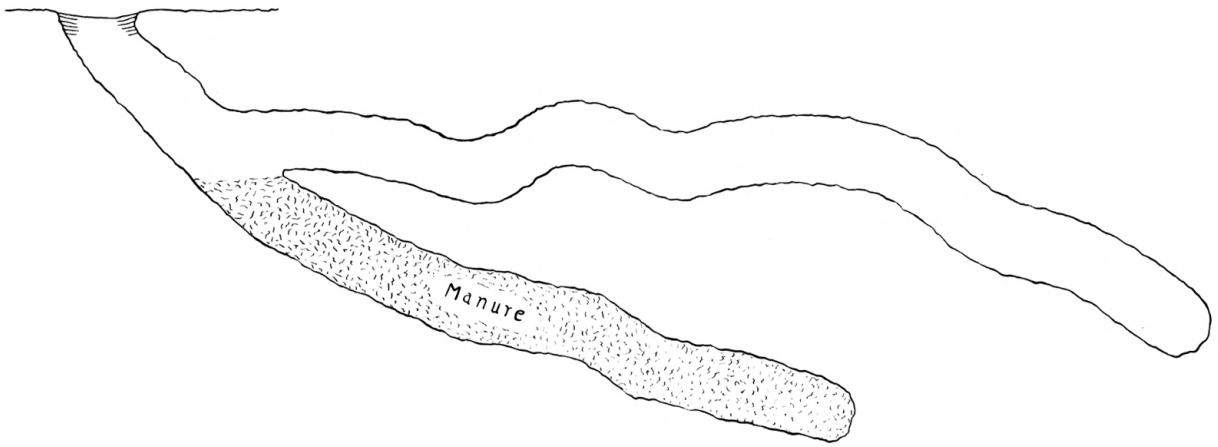

Fig. 1 Pinotus carolinus

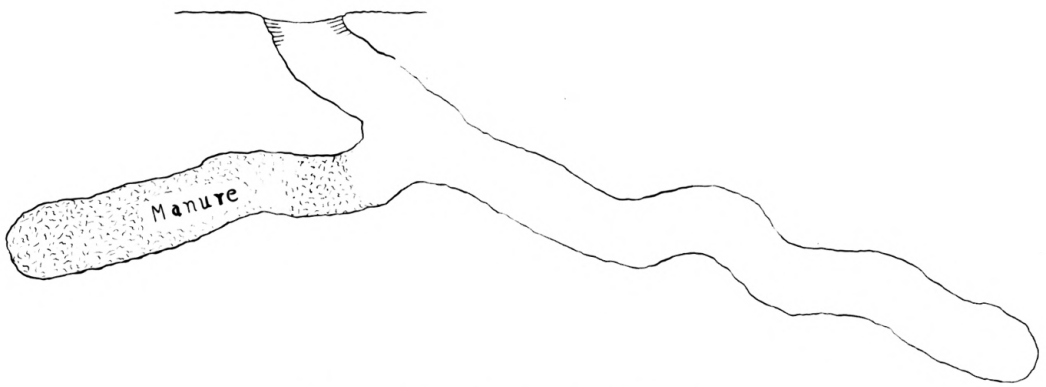

Fig. 2 Pinotus carolinus

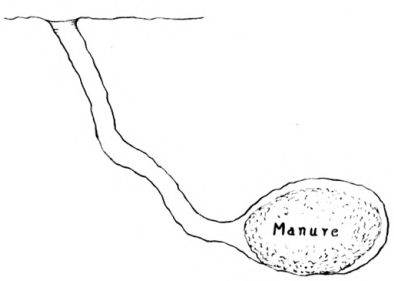

Fig. 3 Copris tullius

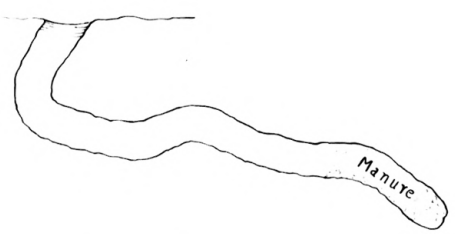

Fig. 4 Phanaeus spp.

PLATE II

Manure Stored by Dung Beetles.

Photograph of manure showing the form in which it is stored by different species of dung beetles. About two-thirds actual size.

Fig. 1. *Onthophagus hecate*

Fig. 2. Pupal cases of *O. hecate*

Fig. 3. *Onthophagus pennsylvanicus*

Fig. 4. *Copris tullius*

Fig. 5. *Pinotus carolinus*

Fig. 6. *Phanaeus* spp.

PLATE II.

Figure 1.

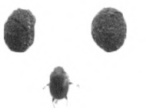

Figure 2.

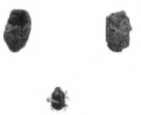

Figure 3.

Figure 4.

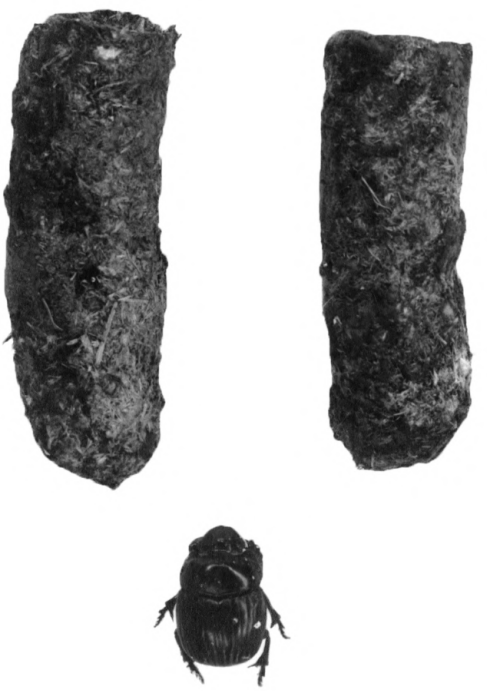

Figure 5.

Figure 6.