ABSTRACT

BERTONE, MATTHEW ALAN. Dung Beetles (Coleoptera: Scarabaeidae and Geotrupidae) of North Carolina Cattle Pastures and Their Implications for Pasture Improvement (Under the direction of D. Wes Watson)

Dung beetles in the families Scarabaeidae (subfamilies Aphodiinae, Scarabaeinae and Coprinae) and Geotrupidae (Geotrupinae) aid in the decomposition of dung, providing many benefits to pasture and animal health. They compete with pestiferous flies and parasitic nematodes for dung resources, enrich the soil by burying large quantities of nutrient-rich dung, and effectively mix and aerate soil through tunneling. Very little is known about the composition of dung beetle species complexes existing in North Carolina cattle pastures or about their seasonal activity. Dung-baited pitfall trapping was conducted for 18 months in cattle pastures of two distinct regions of NC, the piedmont and the coastal plain. Data from a piedmont site and coastal plain site revealed a disparity in species richness (14 and 28 species, respectively) and beetle numbers (20 traps yielding 85,882 beetles and 10 traps yielding 4,111 beetles, respectively). However, both sites had similarly species compositions and were dominated by nine exotic dung beetles. The seasonal activity of 30 species is reported, including two new state records, *Aphodius prodromus* Brahms and *Onthophagus gazella* (Fabricius). These data represent important background information on the relative abundance and richness of dung beetle species in North Carolina.

Two additional studies evaluated the benefit of dung beetles on soil nutrition, and the off-target effects of the insect growth regulator methoprene on dung beetle populations. The activity of two species of tunneling dung beetles (*Onthophagus gazella*...
and *Onthophagus taurus* Schreber) was found to contribute to the general nutrition of three soil types (piedmont clay, coastal plains sandy-loam and play sand) under laboratory conditions. Beetles reproducing in the soils buried dung for brood production, elevating levels of major and minor plant nutrients, as well as altering other soil properties (including pH, cation exchange capacity and exchangeable acidity).

Methoprene was successfully used for the control of the horn fly [*Haematobia irritans* (L.)] in an area-wide program in Nash Co., NC. The trapping of dung beetles in the program area before and after treatment, compared to a pesticide free area, revealed no significant reduction in the populations of several common beetle species. However, additional monitoring, through trapping, is needed to determine the long-term effects of methoprene usage.
DUNG BEETLES (COLEOPTERA: SCARABAEIDAE AND GEOTRUPIDAE) OF NORTH CAROLINA CATTLE PASTURES AND THEIR IMPLICATIONS FOR PASTURE IMPROVEMENT

by

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(Chair of Advisory Committee)
DEDICATION

I would like to dedicate this work to my family. In particular my mom and dad, who have supported my interest in entomology for as long as I can remember, and my aunt Dianna, who passed away just prior to seeing me enter graduate school (I know she would have been proud).
BIOGRAPHY

Matthew Alan Bertone was born on May 27, 1979 to Nan Adelaide and Steven Michael Bertone in New York, NY. At the age of five he, his sister, Lauren Renee, and his parents moved to Lansdale, PA where he spent thirteen years. He attended LaSalle College High School in Wyndmoor, PA with a strong interest in biology, and graduated in 1997. Attending Salisbury State University (now Salisbury University) in Maryland, he majored in biology focusing on zoology. He graduated *Cum Laude* with a BS in biology. In the summer of 2001 he moved to Raleigh, NC to attend graduate school at North Carolina State University. There he worked on an MS degree in entomology under Dr. D. Wes Watson.
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I. Literature Review

Introduction

Dung beetles can be defined as coprophagous members of the Coleopteran families Scarabaeidae and Geotrupidae (Halffter and Matthews 1966). Species in the subfamilies Coprinae and Scarabaeinae (Scarabaeidae) are considered true dung beetles, as well as some species in the Geotrupidae and Aphodiinae (Scarabaeidae) (see the Dung Beetle Species and Taxonomy section of the Literature Review).

Dung beetles are an important component of dung fauna. In many areas they are the dominant species present at vertebrate dung. They exhibit a wide range of ecological, morphological and behavioral adaptations that have helped them become established in the Nearctic, Palearctic, Neotropical, Oriental, Afrotropical and Australian regions of the world (Hanski and Cambefort, 1991).

The vital role dung beetles play in natural ecosystems is strongly reflected by systems in which they are absent or are not adapted to use dung sources present (Bornemissza 1960). The classic example of this occurred in Australia, where introduced cattle produced dung that was not used by native dung beetles. For many years dung pats littered the pasture landscape, reducing the availability of palatable forage for cattle. Bornemissza (1960) suggested that dung-feeding insects, particularly dung beetles, could help remove dung pats in an efficient manner. Other benefits he attributed to dung beetle activity included the following:

(i) burial of nitrogen and nutrient-containing dung
(ii) reduction in accessibility of infective worms to livestock
(iii) reduction of breeding sites for pestiferous flies
(iv) improvement of the permeability and holding capacity of soil to water
Onthophagus gazella (F.) was the first exotic species intentionally introduced into Australia in 1968. This Afro-Asian beetle was mass reared and became established most places it was released, efficiently consuming and burying dung pats in those areas (Bornemissza 1976). Over the following years (1968-1982) the eggs of 52 species of dung beetles were shipped to Australia. Of these, 41 species were reared and released, and 22 became established (Hanski and Cambefort, 1991). Presently, at least one species of introduced dung beetle can be readily collected in the pastures of most regions of Australia.

During 2002, the United States cattle industry maintained 96,704,000 head of cattle, valued at more than $57 billion in dairy products and beef cattle/calves (USDA 2002). North Carolina produced 950,000 head resulting in state receipts valued at about $370 million (NCDA & CS 2002).

Cattle are estimated to produce an average of 10 dung pats per day (Bornemissza 1960, Fincher 1981). Extrapolating from 2002 data, the 634,000 cattle on pasture in NC (beef cows and all heifers, steers and bulls over 500 lbs.) produced about 6,340,000 dung pats per day and nearly 2,314,100,000 dung pats annually (NCDA & CS 2002). If each pat covers about 0.08 m$^2$ of pasture surface, these deposits foul 185,128,000 m$^2$, or 185,128 km$^2$ of North Carolina’s 7,284 km$^2$ of pasture surface per year (Fincher 1981).

Dung beetles were introduced into the U.S. and Canada, but not to the extent of the Australian project. The most notable introduction was the species Onthophagus gazella (F.). It was imported from Australian colonies in 1970 and released in Texas in 1972 for pasture improvement (Blume and Aga 1978). Another important species, Onthophagus taurus Schreber, was accidentally introduced into Florida, and was first
recorded in 1971 (Fincher and Woodruff 1975). It was later intentionally released in several areas including California, Texas and New Jersey (Hoebeke and Beucke 1997). These two beetles have spread throughout much of the eastern U.S., and are efficient in removing dung. Additional species have been colonized and released in the U.S., though they have not been detected in North Carolina (Fincher 1986).

**Dung Beetle Biology, Behavior and Reproduction**

Most dung beetles require dung as a food source during some stage of their lifecycle. Some species are generalists, attracted to and feeding on many types of dung. Others are specialized to groups of animals or, in extreme cases, use the dung of only one species (stenophagy) (Halffter and Matthews 1966). Generally, dung beetles are more attracted to omnivore dung (particularly swine dung), then to herbivore dung and are least attracted to carnivore dung (Fincher et al. 1970). There are a limited number of species that do not feed on dung as adults, but consume other materials such as fungi, carrion, fruit, insect refuse and occasionally other live insects (Halffter and Matthews 1966).

Adult dung beetles in the subfamilies Scarabaeinae, Coprinae and Aphodiinae (family Scarabaeidae) have specialized mouthparts for dung feeding (Halffter and Matthews 1966). The mandibles and maxillae are equipped with fine fringes for manipulating and filtering the semi-liquid constituents of dung. The mandibles also have a large molar area for grinding food particles in the liquid suspension. In contrast, the Geotrupidae have mouthparts less modified to filter dung liquids, but have biting mouthparts reflecting the partially mycophagous diet of the adults (Halffter and Edmonds 1982).
Larvae of all dung beetles have the typical biting mouthparts found in all Scarabaeoid larvae (Halffter and Matthews 1966). When feeding on dung these mouthparts are used to masticate the fibrous materials, such as undigested plant fibers from large herbivore dung, rather than the liquids.

Nesting behavior in these beetles is complex compared to most insects. Dung beetle nidification is extremely variable, and is dependent on species. However, based on the position of the nest relative to the food source, nesting can be sub-divided into three main categories: endocoprid, paracoprid or telecoprid (Bornemissza 1976).

Endocoprid behavior is characterized as nesting within the dung source or in the dung-soil interface. Dung beetles with this nesting behavior rarely supply their larvae with food caches and simply lay eggs inside areas of the food source. This nesting behavior is most frequent in the Aphodiinae and, to a much lesser extent, in the Coprinae (Eurysternus, some Oniticellus and Tragiscus; patterns VI & VII of Halffter and Edmonds 1982).

Paracoprid behavior refers to dung beetles that burrow underneath or near the dung source. Dung burial and nest structure vary between species. The most primitive form of paracoprid nesting consists of dung being packed into the blind end of a tunnel, dug by one or both of the parent beetles (pattern I nesting behavior of Halffter and Edmonds 1982). These brood masses are usually sausage shaped and contain one egg. A soil barrier usually divides each brood mass from sibling masses (unless environmental conditions do not favor single brood masses; Barkhouse and Ridsdill-Smith 1986).

Pattern I paracoprids tend to have high fecundity, but lack nest complexity and intimate brood care (Halffter and Edmonds 1982). In more complex paracoprid nesting, adults
may bury a large quantity of dung and make several brood balls (patterns II & III of Halffter and Edmonds 1982). These balls are usually constructed from a large cake of dung in a chamber created by the adult beetles, or the balls may individually occupy multiple chambers. In some cases the adults will protect the balls by adding a cement-like layer to the surface (as in *Phanaeus*). In other cases the female will guard the balls, cleaning them and restructuring them while the larvae develop (as in *Copris*). Most of the Coprinae and Geotrupidae exhibit paracoprid behavior.

The last form of nesting behavior is termed telecoprid (pattern IV of Halffter and Edmonds 1982). These are the ball-rolling dung beetles. Adults of these species arrive at a dung source and excavate a portion of the dung. The allotment of dung is subsequently formed into a ball which is then rolled to some distance away from the dung pat by either or both parents. The ball is usually buried in a simple, shallow tunnel and a single egg is laid in it. This process is normally repeated several times. The Scarabaeinae are the only dung beetles that exhibit telecoprid behavior.

Other forms of reproductive behavior do exist. For example, *Onthophagus parvus* Blanchard hangs on the hair of the anal region of marsupials to utilize dung when it is dropped (Halffter and Edmonds 1982). *Cephalodesmius armiger*, a scarabaeine beetle, constructs “dung” by collecting partially decomposing leaves, fruit and other plant materials and forming the materials into an artificial pat. The pat decomposes and begins to resemble true dung, at which time the female forms balls from the mass for oviposition (Halffter and Edmonds 1982). Apart from these and other limited examples, however, most dung beetle species will fall into one of the three main groups described above.
Once nests are constructed, larval development varies from species to species. The Scarabaeidae and Geotrupidae have three instars, after which pupation and adult emergence occur. Though the duration of larval development varies with environmental conditions, many species generally take from 30 to 50 days to reach maturity (Halffter and Matthews 1966).

Dung Beetle Species and Taxonomy (U. S. and Canada)

Compared to the Afrotropical and Neotropical regions, the Nearctic region has relatively few species of dung beetles in only a few genera. For example, in the Nearctic region the telecoprids are represented by 24 species in 4 genera. In contrast the Afrotropical and Neotropical regions are home to 450 species in 49 genera and 361 species in 33 genera, respectively (Hanski and Cambefort 1991).

The taxonomy of dung beetles has been studied extensively, and reorganized numerous times. However the present taxonomy of species in the United States and Canada is relatively stable. The following is a listing of the taxonomic classification of the Scarabaeidae and Geotrupidae associated with dung in North America, North of Mexico. Classification of the Scarabaeidae is based on Hanski and Cambefort (1991) with the exception of the Aphodiinae, which is elevated to family status by these authors. The dung feeding Geotrupidae presented here are from Woodruff (1973), but are considered a subfamily of the Scarabaeidae in his work.

FAMILY SCARABAEIDAE

Subfamily SCARABAEINAЕ

Tribe Canthonini
Genus *Deltochilum*

Genus *Canthon* (including *Glaphyrocanthon* and *Boreocanthon*)

Genus *Melanocanthon*

Genus *Pseudocanthon*

**Subfamily COPRINAE**

Tribe Dichitomiini

Genus *Ateuchus*

Genus *Dichotomius*

Tribe Coprini

Genus *Copris*

Tribe Phanaeini

Genus *Phanaeus*

Tribe Onthophagini

Genus *Onthophagus*

Tribe Oniticellini\(^1\)

Genus *Liatongus\(^1\)*

Genus *Euoniticellus\(^1\)*

Tribe Onitini\(^1\)

Genus *Onitis\(^1\)*

**Subfamily APHODIINAE**

Tribe Aphodiini

Genus *Aphodius*

Tribe Eupariini
Genus *Ataenius*

**FAMILY GEOTRUPIDAE**

Subfamily Geotrupinae

Tribe Geotrupini

Genus *Geotrupes*

Genus *Peltotrupes*

Genus *Mycotrupes*

1 New tribes and genera released in the U.S. (Fincher 1986)


**Regional and Local Dung Beetle Assemblages**

Surveys of North American dung beetle fauna, North of Mexico, have previously been conducted in several areas. Recently studied areas include Texas (Nealis 1976, Howden and Scholtz 1986, Fincher et al. 1986, Howden and Howden 2001), Georgia (Fincher 1975a, Fincher 1979, Fincher and Woodruff 1979), Florida (Woodruff 1973), South Dakota (Kessler et al. 1974), Minnesota (Cervenka and Moon 1991) and Alberta, Canada (Floate and Gill 1998). Blume (1985) compiled a comprehensive checklist, distribution and bibliography of dung inhabiting insects, including dung beetles, of America North of Mexico.

Dung beetle assemblages vary greatly at different latitudes. In North temperate latitudes the Aphodiinae and Geotrupidae dominate the dung beetles found in bovine dung. As sampling continues into more southern latitudes, species of the Scarabaeeinae and the Coprinae begin to dominate the dung beetle fauna (Halffter and Matthews 1966, Hanski and Cambefort 1991). Floate and Gill (1998) surveyed two sites in southern...
Alberta, Canada, to determine the species of dung beetles existing in that region. Trapping yielded 17 species over three years. Included in these species were one species in the Coprinae [*Onthophagus nuchicornis* (L.)], one species in the Scarabaeinae (*Canthon praticola* LeConte) and one species in the Geotrupidae (*Bolboceras* sp.). The remaining 14 species were all in the genus *Aphodius*. Although the introduced *O. nuchicornis* comprised the largest percentage (38.6%) of any species trapped over the three years, *Aphodius* species comprised most of the remaining species.

In contrast to the *Aphodius* rich North temperate regions, southern regions, such as Texas, are dominated by the Scarabaeinae and Coprinae. Fincher et al. (1986) studied dung beetles in open and wooded pastures in East-Central Texas. From March of 1979 through November of 1980, 35 species of dung beetles were trapped. Thirteen species represented aphodiine dung beetles (11 *Aphodius* spp. 1 *Didactylia* sp. and 1 *Ataenius* sp.) and two species were represented from the Geotrupidae (both *Geotrupes* spp.). The remaining 20 species belonged to the Coprinae (9 *Onthophagus* spp., 1 *Ateuchus* sp. and 2 *Phanaeus* spp.) and Scarabaeinae [5 *Canthon* spp. (including *Glaphyrocanthon* and *Boreocanthon*), 1 *Deltochilum* sp., 1 *Melanocanthon* sp. and 1 *Pseudocanthon* sp.].

Local habitats contribute to dung beetle distribution and species composition as well. Soil is perhaps the most important factor influencing the local distribution of dung scarabs (Halffter and Matthews 1966, Nealis 1976). Nealis (1976) studied various habitats in South Texas to determine the relationship between dung beetle (Scarabaeinae and Coprinae) distribution and local landscapes. He found that the majority of species present at his study site preferred sandy soil to clay soil (11 of 16 species). He concluded that dung beetles construct tunnels more easily in sandy soils than clay soils. The ability
to produce more tunnels, and thus more offspring, in sandy soil would increase a beetle’s fecundity. Increased fecundity of beetles inhabiting sandy areas would then increase population sizes and lead to a greater chance for diversity.

Nealis (1976) studied shade (or its lack) and type of vegetational cover in relation to species composition, and found shade to be the next most important factor contributing to dung beetle distribution next to soil type. Of the 16 species, seven were found most commonly in the open, while 5 were found mostly in shaded areas; 4 had no preference. Nealis found cover type to have very little effect on species composition.

Resource Competition: Fly and Worm Control Potential

Through their actions, dung beetles affect other organisms that live in and feed on dung. These effects can be detrimental to pest species. By reducing the breeding habitat for nuisance flies and the larvae of gastrointestinal parasites, dung beetles act as an indirect form of biocontrol. This aspect of their behavior makes them valuable to cattle farmers around the world.

The benefit provided by dung beetles as biological control agents (though not in the classical sense) of nuisance flies has been studied extensively. Five main nuisance flies (Diptera: Muscidae) are considered important pests because of their injurious effects on cattle. These are the horn fly (Haematobia irritans irritans (Linnaeus)), the face fly (Musca autumnalis De Geer), the African buffalo fly (Haematobia thirouxi potans (Bezzi)), the Australian buffalo fly (Haematobia irritans exigua (de Meijere)) and the bush fly (Musca vetustissima Walker). These species have been widely introduced.
throughout the world into areas where cattle are raised. All lay eggs in cattle dung, where
the larvae feed and mature.

In the absence of telecoprid and paracoprid dung beetles, up to 39 ± 4.1% of
African buffalo fly eggs reached maturity in a field study in Africa (Fay and Doube
1983). When either telecoprids or paracoprids were added to comparable dung pats in
ratios similar to those found in nature, buffalo fly survival was reduced to 5.1 ± 1.2% and
6.4 ± 2.6% respectively. Doube and Moola (1988) introduced a large (1-2 g dry weight)
paracoprid species, *Catharsius tricornutus* De Geer, into pats containing eggs of the
African buffalo fly to determine it’s impact on fly survival. The activity of two pairs of
beetles reduced fly emergence from 23.2 ± 3.9% to 13.9 ± 2.6%. With the addition of 8
pairs of beetles, fly emergence was reduced to only 1.5 ± 0.6%.

The Afro-Asian dung beetle *Onthophagus gazella* has been the focus of various
studies on dung-breeding fly survival. Efficient at burying dung, *O. gazella* has been
introduced into various countries for fly control (Bornemissza 1976, Blume and Aga
1978). Bush fly survival was reduced significantly when *O. gazella* was introduced to
dung pats containing fly eggs (Bornemissza 1970). With no beetle pressure (in 1000 cc
pats), an average of 90.7 offspring emerged from the eggs of 10 female bush flies. The
introduction of 10 pairs of *O. gazella* reduced fly survival to 7.5, and as little as 20 pairs
of *O. gazella* reduced survival to 0.0.

Multiple factors contribute to the dung beetle-induced mortality of dung breeding
flies. One factor is the life stage at which flies are exposed to dung beetle activity. Fly
eggs in dung with beetle activity are more affected than established fly larvae.

Bornemissza (1970) compared the survival of flies produced from the eggs of 5 gravid
females, on 100 cc dung pats, with 50 larvae seeded on the same size pats. Similar mean survival numbers occurred in the controls (44 and 39.5 respectively). However, when beetles were introduced at densities of 1, 2, and 3 pairs, mean survival of bush fly eggs was 4.5, 2.5 and 0.0 respectively, while the larval survival was 22.5, 11.8 and 8.0.

The size of dung pats can influence fly survival under beetle pressure. Blume et al (1973) showed that 30 pairs of *O. gazella* could control 83.7% of fly emergence in dung pats weighing 454g, but could only control 29.1% of the flies in a pats double the size. This demonstrates that dung beetles control flies by resource competition, rather than by direct mortality.

Many other factors contribute to the potential for fly control by dung beetles including infrared radiation (Doube and Moola 1988), seasonal coincidence of dung beetles and pest species (Macqueen and Beirne 1975a, Roth et al. 1988) and the amount of dung buried by a species (Macqueen and Beirne 1975a). Though the degree of fly control varies with different conditions, dung beetles have a controlling effect on dung breeding flies, if only minor in some cases.

Another injurious group of organisms that breeds in dung are endoparasites of cattle. Endoparasitic worms live and breed in the digestive tract of cattle, lay eggs and the eggs are subsequently defecated onto the surface of the ground. The eggs hatch and mature in the moist environment of dung. When they reach the infective stage of their life, the worms travel across the soil surface or grass through a film of liquid. They are ingested by any cattle grazing on the worm-infested forage and complete their lifecycle in the digestive tract of the animal.
Bryan (1972) tested the effects of *O. gazella* on the mortality of strongyle worm larvae [*Haemonchus placei* (Place 1893), *Cooperia pectinata* (Ransom 1907) and *Oesophagostomum radiatum* (Rudolphi 1803)] in dung pats in irrigated and non-irrigated pastures. When dung pats were left intact, without dung beetle activity, helminth recovery from vegetation surrounding the pats was high. As expected, the vegetation around dung pats with beetle activity showed far less helminth larvae. Interestingly though, the recovery of helminth larvae around pats with low beetle densities was less than those with higher beetle densities. Bryan attributed this to helminth larvae being buried by the beetles. At high densities of beetles, more dung containing helminth larvae was buried and these larvae survived in the moist soil, traveling to the surface under wet conditions. When beetle densities were low, less helminth containing dung was buried. However, sufficient destruction of the dung pats reduced the larvae recovered from the surrounding areas.

Fincher (1975b) studied the effects of dung beetles on the number of parasitic worms that were acquired by uninfected calves on pasture. He used three adjacent pastures of similar size, and contaminated each by putting infected steers on the plots. Each plot was then subjected to low, natural or high dung beetle densities. A high density plot was created by adding 1,500 *Phanaeus vindex*, *P. igneus* and *Dichotomius carolinus*, initially and augmenting the population with beetles throughout the experiment. Two uninfected calves were placed on each plot with the infected steers after sufficient time for dung beetle activity. They were allowed to graze and were subsequently necropsied to count any worms. A total of six different species of nematode worms were found in the calves (*Ostertagia ostertagi*, *Haemonchus placei*, *Cooperia pectinata*, *Cooperia*...
oncophora, Cooperia punctata and Oesophagostomum radiatum). Calves that grazed the low-density plot had an average of 21,513 individual worms. Those that grazed the natural density plot contained an average of 9,582 worms. Calves that grazed the plot with higher than natural dung beetle density had the lowest number of worms, averaging 2,404 worms per calf.

It should be noted, however, that dung beetles have been implicated in the transmission of parasitic worms and other organisms, by acting as intermediate hosts (Stewart and Kent 1963, Fincher 1975b, Fincher and Marti 1982, Mathison and Ditrich 1999). Beetles may ingest worm eggs without killing them, and harbor the infective stage in their hemolymph. They can then infect livestock if they are consumed accidentally. It is therefore reasonable to say that under certain conditions dung beetles can be beneficial in reducing worm numbers, while under other circumstances they can have a neutral or potentially enhance worm transmission in cattle.

**Effects of Methoprene on Dung Beetles**

Methoprene (isopropyl 11-methoxy-3,7,11-trimethyl-2,4-dodecadienoate) is an insect growth regulator (juvenile hormone analog) used to control many insect pest species. It has been shown to be effective against several dung-breeding fly species, including Stomoxys calcitrans (L.), Haematobia irritans, Musca domestica and M. autumnalis (Harris et al. 1973, Miller and Uebel 1974).

Methoprene may be administered to cattle orally, through either a bolus or a mineral supplement. It is excreted in the dung of treated animals and affects dung feeding
pests. Concern over methoprene’s activity against beneficial organisms (in particular dung beetles) has been debated, especially with studies showing conflicting evidence.

Blume et al. (1974) found that cattle fed methoprene (in a gelatin capsule) at a rate of 1mg/kg produced dung that reduced *Onthophagus gazella* survival by 1.8% the day after treatment and 32.6% by day five. They also found as little as 5 ppm of methoprene (52.5% EC) mixed directly into dung could cause 33.3% mortality in *O. gazella*. One-hundred percent (100%) mortality was achieved by mixing 100 ppm of methoprene into dung. Adult beetles emerging from treated dung, however, were normal and produced normal offspring.

Fincher (1991) treated an animal with 3.8 mg/kg of methoprene in bolus form and subjected the dung beetles *Onthophagus gazella* and *Sisyphus rubrus* Pachalidis to its dung. He found no significant difference between the percent of adult eclosion in beetles using the control dung and those using the treated dung. Horn flies, however, feeding on the same treated dung experienced a 95.3% reduction in adult emergence even after 15 weeks post-treatment.

**Dung Burial, Soil Nutrition and Plant Benefits Attributed to Dung Beetle Activity**

Dung beetles inadvertently help to remove dung from pastures and return it to the soil by burying dung in large quantities to feed their young. This process provides many benefits to agriculture and ecosystems, including making nutrients available for use by plants.

The rate of dung burial depends on a number of factors. One factor is the abundance of beetles in a particular area. For example, areas of Australia that contain a
higher density of introduced dung beetles (both in number of species and dry weight) were observed to have more rapid dung burial than areas that had lower numbers of beetles (Tyndale-Biscoe 1994).

Changes in beetle activity during the year can also affect the amount and rate of dung disappearance. Lindquist (1933) noticed dung beetle activity between early May and the beginning of fall in Kansas cattle pastures. He excavated the nests of several large Coprinae, including *Dichotomius carolinus* (cited as *Pinotus carolinus*), *Copris fricator* (F.) (cited as *C. tullius* Olivier) and *Phanaeus* spp. [*Phanaeus vindex* (cited as *P. carnifex* L.) and *P. difformis* LeConte] to determine the amount of dung buried by each. Lindquist found that *D. carolinus* buried an average of 48.5 grams of dung per nest, *C. fricator* buried an average of 7.26 grams of dung and *Phanaeus* spp. buried an average of 9.62 grams of dung. He also found that nests with two occupants had more dung buried than those with only one. After peak activity during the summer, beetles made deep burrows without burying dung. They remained at the ends of these burrows apparently to over-winter. Thus these species do not bury any dung that may be deposited during winter months.

The size of a beetle species will also determine the amount of dung that it buries. Larger beetles require more dung for development and tend to bury more dung than do smaller species. In India, Mittal (1993) compared the dung burying capacity of three dung beetle species with varying sizes. He found that two male and female pairs of *Onitis virens* Lansberge, *Onitis philemon* F. and *Onthophagus catta* (F.) buried an average of 43.8 ± 6.1, 21.2 ± 0.9 and 1.6 ± 0.2 grams of dung, respectively. Dung burial and the size of the beetles were related to the diameter and depth of each species’ burrows (1.5 and
30.9 cm for *O. virens*, 1.2 and 22.7 cm for *O. philemon*, and 0.6 and 9.3 cm *O. catta*, respectively). Horgan (2001), while quantifying dung burial in El Salvador noted that there was a correlation between the dry weight of female beetles and the amount of dung buried within the first seven days of colonization.

Additional factors that determine the amount of dung buried by beetles in a particular area exist. Lifetime fecundity, adult longevity, soil type and climatic conditions all play key roles in determining how much of the available dung will be buried by beetles. Even the type of food an animal eats can affect the amount of dung that beetles bury for their offspring (Dadour and Cook 1996).

The re-introduction of nitrogen into soil is an important result of the burying capabilities of dung beetles. Dung can contain from 1-3% nitrogen by weight (Macqueen and Beirne 1975b, Mittal 1993, Dadour and Cook 1996). In Canada, Macqueen and Beirne (1975b) showed that at a rate of five pairs of the dung beetle *Onthophagus nuchicornis* (L.), burial of 37% of a dung pat could be accomplished. This calculated to a return of about 134 kg of N per hectare. In areas where larger and more fecund or vigorous beetles are present, beetles may bury 80-95% of the nitrogen in dung (Gillard 1967). Large amounts of nitrogen returned to soil could prove to be an important factor in the growth of plants.

Bornemissza (1970) was the first to experimentally show the direct effects of dung beetle activity on plant growth. He used the small Australian dung beetle, *Onthophagus australis* Guérin, to determine its effects on the growth of Japanese millet, *Echinochloa frumentacea* Link (cited as *Echinochloa crus-galli* var. *frumentacea* Wight), in the laboratory. He found that when dung was applied to the surface of pots, without
beetle activity, millet yield was 17.3 g in the tops and 12.7 g in the roots. When 20 pairs of *O. australis* were allowed to bury the same amount of dung in the pots, plant yield was increased to 31.3 g in the tops and 14.7 g in the roots. This increase was comparable to the 32.1 g in the tops and 14.0 g in the roots produced by the addition of phosphorus [0.3 g Ca(H$_2$PO$_4$)$_2$H$_2$O] and nitrogen (0.3 g NH$_4$NO$_3$) to similar pots without dung or beetles. This is equivalent to a fertilization rate of 150 kg of the same N and P combination per hectare of pasture (or 60 kg per acre).

Macqueen and Beirne (1975b) studied the effects of *O. nuchicornis* on the growth of beardless wheatgrass, *Pseudoroegneria spicata* (Pursh) A. Löve ssp. *inermis* (Scribn. & J.G. Sm.) A. Löve (cited as *Agropyron spicatum* var. *inerme* Heller), in British Columbia (Canada). Using similar methods as Bornemissza (1970), Macqueen and Beirne applied different treatments to pots of soil. Treatments included, but were not exclusive to, soil alone (control), dung alone on the surface, 5 pairs of beetles plus dung and the use of commercial fertilizers. Though plant yield did not differ significantly when dung beetles buried dung, the amount of crude protein increased 38% over the control compared to a 17% increase for dung added alone. Commercial fertilizer at 269 kg N/ha, however, produced the greatest increase over the control, with 144% more crude protein.

In 1981, Fincher et al. observed the yield of coastal bermudagrass [*Cynodon dactylon* (L.) Pers.], when exposed to different treatments in the field. He applied treatments to large plots in a standing pasture. Treatments included dung alone, dung plus 11 species of beetles, and several plots fertilized at different rates. The plots that received dung beetle activity had significantly higher yield over the season (7,791 kg DM/ha) than those without dung beetles (6,364 kg DM/ha) and those that received fertilizer at a
rate of 112 kg N/ha (5,369 kg DM/ha). Furthermore, the yield from the dung beetle plots
was not significantly less than plots that received fertilizer at a rate of 224 kg N/ha (8,305
kg DM/ha).
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II. Seasonal activity and species composition of dung beetles (Coleoptera: Scarabaeidae and Geotrupidae) inhabiting cattle pastures in North Carolina (USA)

Abstract

Dung beetle species composition and seasonal distribution were studied within two distinct regions of North Carolina. Study sites were located in the piedmont (North Carolina Department of Agriculture Piedmont Research Station, Salisbury, NC) and the coastal plain (NCDA Center for Environmental Farming Systems, Goldsboro, NC). Dung beetles were trapped in cattle pastures from March of 2002 through September of 2003 using baited pitfall traps. Ten traps were used at the research station dairy in Salisbury. Twenty traps were used at the research station in Goldsboro, and were divided equally among a dairy unit and a beef unit. Trapping yielded 4,111 beetles representing 14 species from the piedmont dairy. Totals of 57,026 beetles representing 28 species and 28,857 beetles representing 26 species were trapped from the dairy unit and beef unit in the coastal plain, respectively. The introduced beetle *Onthophagus taurus* Schreber accounted for more than 50% of the total beetles caught at both sites. Beetle activity was greatest from March until November of both years, with activity declining during the colder winter months. Nine species in two genera, *Onthophagus* and *Aphodius*, were exotic dung beetles and represented nearly 95% of the beetles trapped. Two species, *Onthophagus gazella* (F.) and *Aphodius prodromus* Brahm, are new records for North Carolina.

**Keywords**: Dung beetles, cattle pastures, seasonal activity, North Carolina
**ARTHROPODS**, including insects that use manure for food and shelter, are instrumental to the decomposition process of cattle dung. Pest insects such as the horn fly, *Haematobia irritans* (L.), and the face fly, *Musca autumnalis* (DeGeer) breed in cattle dung. As adults these flies are of economic importance because they inflict severe irritation on cattle, reducing weight gain, and can transmit diseases (Haufe 1982, Gerhardt et al. 1982). Scarabaeoid dung beetles [Scarabaeidae (Scarabaeinae, Coprinae and Aphodiinae) and Geotrupidae (Geotrupinae)] represent another economically important, but beneficial group of dung arthropods. Benefits attributed to dung beetles are numerous and highly diverse (Bornemissza 1960, 1976, Fincher 1981). Dung beetles compete with dung breeding Diptera for resources, greatly impacting the survival of many pest species (Bornemissza 1970, Blume et al. 1973, Fay and Doube 1983, Doube and Moola 1988). Dung beetles also reduce the survival of endoparasitic nematodes that live in dung pats (Bryan 1973, Fincher 1975). Lastly, many species enhance soil fertility by burying dung for their offspring. Nutrients in the buried dung become available to plants, increasing the quality and amount of plant material on the pasture surface (Bornemissza and Williams 1970, Macqueen and Bierne 1975, Fincher et al. 1981).

Though extensive work has been published on the beneficial actions of dung beetles, surveys of North American dung beetle fauna, North of Mexico, have been conducted in relatively few areas. Recently studied areas include Texas (Nealis 1977, Howden and Scholtz 1986, Fincher et al. 1986, Howden and Howden 2001), Georgia (Fincher 1975, Fincher 1979, Fincher and Woodruff 1979), Florida (Woodruff 1973), South Dakota (Kessler et al. 1974), Minnesota (Cervenka and Moon 1991) and Alberta,
Canada (Floate and Gill 1998). Many areas still lack adequate information on local species, their relative abundance and their seasonal activity.

In 2002, North Carolina cattle producers raised 950,000 head of cattle valued at an estimated $216 million. Of these cattle 434,000 were beef cows while 66,000 were dairy cows (with calves, steers, heifers, and bulls comprising the remaining 500,000 cattle), (NCDA & CS 2003). Most beef producers raise their cattle on pasture for much of the year and, recently, numerous dairy producers have begun to graze cattle on pasture. This practice reduces nuisance fly issues, odors and environmental concerns for the accumulated dung associated with confinement systems (Thomas and Skoda 1993). However, dung left on pasture provides breeding grounds for pest fly species such as the horn fly, an insect already abundant in the state.

Very few studies have focused on the dung beetle fauna of North Carolina, and none have focused on cattle pastures in the state (Davis 1966). Such studies play an important role in understanding insect biodiversity, monitoring the progress of introduced species and providing essential ecological information on how native species respond to non-native species. My goals in this research were to (1) determine the species of Scarabaeidae and Geotrupidae existing at two different sites in North Carolina, (2) assess the dominant species occurring at these two sites and (3) follow the seasonal activity of each species throughout the year.
Materials and Methods

Two geographically distinct sites were selected for the study, one located in the Piedmont region of central North Carolina and the second on the Coastal Plain of eastern NC. The Piedmont Research Station in Salisbury (Rowan Co.; N 35.7° latitude, W 80.62° longitude; 251 m above sea level) is located in the piedmont region of western North Carolina. It is in the felsic crystalline soil system and local soil consists of Hiwassee and Starr clay loam (Daniels et al 1999). The dairy unit maintains an average of 200 Holstein milking cows milked twice daily. Approximately 150 cows, heifers and calves were on pasture during the study.

Forage species found on this farm consist of tall fescue (*Festuca arundinacea* Schreb.), rescuegrass (*Bromus catharticus* Vahl) and, to a lesser extent, bermudagrass [*Cynodon dactylon* (L.) Pers.] and white clover (*Trifolium repens* L.). Cattle were also supplemented with corn silage.

The Center for Environmental Farming Systems (CEFS) (Wayne Co.; N 35.44° latitude, W 78.09° longitude; 41 m above sea level) in Goldsboro is located in the coastal plain region of eastern NC. It is in the middle coastal plain soil system and has various soil types including Johns sandy loam, Kenansville loamy sand, Rains sandy loam and Torhunta loam (Daniels et al. 1999). This station has an operating beef unit as well as a dairy unit. The beef unit averages 125 Black Angus cows and replacement heifers, including several Angus/Senepol crossed cattle. The dairy unit averages 140 Holstein and Holstein/Jersey mixed lactating cows and 35 calves. All cattle are kept on pasture the entire year. The dairy herd is brought in twice daily for milking.
Forage species at CEFS include Coastal bermudagrass [*Cynodon dactylon* (L.) Pers.], rescuegrass (*Bromus catharticus* Vahl, cv Matua), pearl millet [*Pennisetum glaucum* (L.) R. Br.], rye (*Secale cereale* L.) and annual ryegrass (*Lolium multiflorum* Lam.). Crabgrass (*Digitaria sanguinalis* (L.) Scop.) and dallisgrass (*Paspalum dilatatum* Poir.) are also abundant on this farm. In addition to grazing, dairy cattle were fed corn silage and haylage. During the winter beef and dairy cattle are fed cottonseed, gin trash and hay in addition to the available forages found in the pastures.

Dung beetles were captured using manure-baited pitfall traps similar to those developed by Floate 1998 (Figure 1). Fresh bovine dung was collected from pastures at each unit and frozen until needed. Dung beetle baits were prepared by wrapping an aliquot of thawed dung, measured using a 55 ml ice-cream scoop, in a white paper towel (approximately 6 by 2.5 cm) (Figure 1). These balls served as baits for the pitfall traps. Dung baits were frozen until they were required for field trapping.

The pitfall traps were inserted into 10.2 cm diameter, thin walled (2 mm) polyvinyl chloride (PVC) tubes buried to a depth of 25 cm. The tubes prevented the collapse of soil into the hole and provided assurance of repeated and precise trap placement. Trapping initially occurred weekly, beginning March 7, 2002, with traps remaining in the field for a 24-hour period. We saw no advantage to continuing the weekly trapping schedule and changed the trapping interval to one 24-hr period every two weeks, starting April 10, 2002. This trapping interval was maintained through September of 2003. Climatological data were recorded by stations at each site and supplied by the State Climate Office of North Carolina (SCO) (Figures 5 and 6).
Ten traps were placed in the dairy unit of the Piedmont Research Station (Figure 2). Five traps were located on the western side of the farm, between several dry-lot paddocks and pastures. The remaining five traps were placed on the eastern side of the unit in a pasture where cattle were constantly kept. Traps were placed approximately 10 m apart and were located under the electrical fencing for protection from cattle.

Twenty traps were located at CEFS. Ten traps each were assigned to the dairy unit and the beef unit. Traps were separated by approximately 50 m. Although the number of traps used at each unit remained constant (10), the trap location varied during the study (Figures 3 & 4). As the cattle herd moved from pasture to pasture under the rotational grazing scheme, the traps were placed nearest to pastures with cattle present. Occasionally trap locations were changed from high traffic areas and flooding prone areas that inhibited dung beetle trapping.

After 24 hours beetles from the traps were collected in plastic bags, labeled according to location, and returned to the laboratory where the beetles were identified and counted. Species were identified using the keys in Howden and Cartwright (1963), Woodruff (1973), Gordon (1983) and Harpootlian (2001). Voucher specimens were placed in the insect museum of North Carolina State University, Department of Entomology, Raleigh, NC.

To determine if trap location played a role in trap yields, a correlation between distance to cattle and trap yield was calculated using SAS 8.2 (PROC CORR, SAS Institute 2001). Data from seven consecutive trapping dates (Goldsboro dairy unit) during the summer of 2003 were chosen to calculate correlation coefficients. Trap yields of an
aphodiine species, *Aphodius lividus* Olivier, and a coprine species, *Onthophagus taurus* Schreber, were used in the calculation.

Chi-square ($\chi^2$) analysis was used to determine if captured beetles were randomly distributed among baited traps from the Goldsboro dairy unit. Trapping data from the first trapping date of May, June, July, August and September of 2002 and 2003 were used for the analysis. Observed total trap catches were used to calculate the probabilities. Chi-square values exceeding the critical value of 15.5 [8 df (10-2) at $\alpha \leq 0.05$] were rejected.

**Results**

Cattle on the test farms were under a rotational grazing program to maximize available forages. Trap locations were selected to approximate the location of the cattle. Although the distance from pastured cattle to the traps varied, distance did not contribute significantly to trap yield variability. Correlation coefficients calculated for the relationship between the distance of traps to cattle and trap yield ranged from $r = 0.445$ to $r = -0.781$ for *O. taurus*, and from $r = 0.499$ to $r = -0.568$ for *A. lividus*. No calculated coefficients reflected a strong relationship.

The number of beetles captured in the baited traps was not uniformly distributed among the traps during periods of peak beetle activity (Tables 1 and 2). Chi-square ($\chi^2$) values exceeding predicted values for random distributions were rejected ($\alpha \leq 0.05$). Based on $\chi^2$ values, dung beetles were contagiously distributed between the traps each month during the summer except August of 2002 ($\chi^2 = 13.7$, df = 8). Total number of beetles captured during August, 2002 were lower than other months presumably because of high temperatures and little rainfall (Figure 6).
During the study 89,993 dung beetles were trapped, encompassing 30 species in 8 genera (Table 3). Trapping in Goldsboro yielded 85,882 beetles, with the dairy unit contributing 57,025 of these individuals and the beef unit contributing 28,857. Traps from Salisbury yielded fewer beetles, with only 4,111 beetles trapped during the 18 months. Similarly, the number of species trapped from each site differed resulting in only 14 species (6 genera) taken from the Salisbury, compared to 28 species (8 genera) taken from Goldsboro (Table 3). Nine of the 30 species taken during this study are exotic species, and these dominated the dung beetle fauna at each site (Table 3). Ninety-five percent (95.4%) of all beetles trapped from the CEFS dairy unit were introduced into North America while 90.5% of the beetles trapped from the beef unit were introduced. In Salisbury, 94.0% of the beetles trapped were introduced species. Only *Onthophagus gazella* (F.) was introduced intentionally, being released into Texas in 1970 for pasture improvement (Blume and Aga, 1978). The remaining 8 species were accidental introductions, mainly from Europe (*Aphodius* spp.: Gordon, 1983; *O. taurus*: Fincher and Woodruff, 1975).

Based on the number of species and specimens caught, the period of greatest beetle activity occurred from late winter (March) through late autumn (November) at both sites. Beetle activity greatly diminished when temperatures fell below 10°C. An additional period of reduced activity occurred during August of 2002, when little or no rain fell and the maximum daily temperatures often exceeded 30°C (Figures 5 and 6).

Species composition is the percentage of the total comprised by each species. Dominant species are considered to make up more than 5% of the population (Howden and Scholtz 1986). Throughout the entire study the most dominant species were
Onthophagus taurus, Aphodius lividus, Aphodius erraticus (L.), Onthophagus gazella and Onthophagus pennsylvanicus Harold. Less dominant (1-5%) but still common species included Aphodius granarius (L.), Aphodius distinctus Müller and Onthophagus hecate hecate Panzer.

A total of 54,929 O. taurus was trapped from Goldsboro (Table 3). In contrast, only 2,729 O. taurus were trapped from Salisbury. This species represented 63.96 and 66.38% of the population in Goldsboro and Salisbury, respectively. More Onthophagus taurus were trapped from the Goldsboro dairy unit (41,829 beetles representing 73.35% of the population) than the beef unit (13,100 beetles representing 45.40% of the population). Onthophagus taurus was active during the warmer months of the year, including late March through late October and early November. Peaks in activity occurred in June of 2002 in Goldsboro (>11,000 beetles trapped) and late August of 2002 in Salisbury (>1,600 beetles trapped) (Figure 7).

Aphodius lividus comprised 18.39% (15,759 individuals) of the beetles trapped from Goldsboro and 18.88% (776 individuals) of the beetles trapped from Salisbury (Table 3). The beef unit in Goldsboro trapped more A. lividus that the dairy unit, 8,938 and 6,857 beetles respectively. In addition this species represented more of the population at the beef unit (30.97%) than the dairy unit (12.02%). Aphodius lividus had a long period of activity with beetles being taken from early March through late November and early December at both sites (Figure 8).

Aphodius erraticus was abundant at both sites making up 5.47 and 5.53% of the total dung beetle collections from Salisbury and Goldsboro, respectively (Table 3). More A. erraticus were caught in Goldsboro than Salisbury (4,755 and 225 respectively). The
Goldsboro dairy unit yielded more *A. erraticus* than the beef unit, with traps collecting 3,419 and 1,336 individuals respectively. This species made up 6.00% of the population at the dairy unit and 4.63% at the beef unit. *Aphodius erraticus* had a short season of activity, being active from early March until early July at both sites (Figure 9).

*Onthophagus gazella* was taken exclusively from Goldsboro (Table 3). A total of 1,927 individuals of this species was taken from the beef unit, comprising 6.68% of all beetles trapped there. Traps from the dairy unit caught 2,040 *O. gazella*, making up 3.58% of total collections. *Onthophagus gazella* activity was from May through early November of 2002, with peak activity during August, September and October (Figure 10). During 2003, activity was observed from June until the end of trapping.

*Onthophagus pennsylvanicus* was common at both sites. One-hundred and forty specimens (3.41% of the total population) of this species were taken from Salisbury during the study (Table 3). Goldsboro traps yielded 3,595 *O. pennsylvanicus* individuals, comprising 4.19% of the population. Of the individuals taken in Goldsboro, 1,699 individuals were from the dairy unit while 1,896 were from the beef unit. *Onthophagus pennsylvanicus* represented 2.98% of the beetles taken from the dairy unit and 6.57% of the beetles taken from the beef unit. This species was active during most of the year, particularly from late March through early November (Figure 11).

*Aphodius granarius* was most abundant at Salisbury with traps yielding 103 specimens (2.51% of the population) (Table 3). Collections from the Goldsboro dairy were much smaller, 15 specimens total, representing 0.03% of the beetles taken. Collections from the beef unit yielded 72 *A. granarius* representing 0.25% of the population. All together, 87 individuals of this species were trapped from Goldsboro.
representing only 0.10% of the population. The seasonal activity of *Aphodius granarius* was similar to that of *A. erraticus*, with individuals taken from the late winter until the early summer (Figure 12).

*Aphodius distinctus* was most abundant (845 specimens) on the CEFS beef unit, representing 2.28% of the beetle population (Table 3). Only 188 individuals were collected from the CEFS dairy unit (0.33% of the total). A single individual was trapped from Salisbury during the study. *Aphodius distinctus* was abundant during the cooler months of autumn and winter, with fewer individuals being trapped during the spring (Figure 13). No specimens were collected during the summer months.

*Onthophagus hecate hecate* was common at both sites with 87 and 884 individuals taken from Salisbury and Goldsboro, respectively. *Onthophagus h. hecate* comprised 2.12% of the beetles trapped from Salisbury and 1.03% of the beetles in Goldsboro. More *O. h. hecate* were trapped from the Goldsboro dairy unit (530) than the beef unit (354), though this species made up a higher proportion of the population at the beef unit (1.23% versus 0.93% for the dairy unit). *Onthophagus h. hecate* was present during much of the year at both sites, emerging in March and active through the summer (Figure 14). Individuals were trapped through November and, rarely, in December and January. This subspecies is replaced by another subspecies, *O. hecate blatchleyi* Brown, in Florida.


*Onthophagus taurus* dominated the beetle fauna during all seasons except the winter at the two dairies (Tables 4-7). At the Goldsboro beef unit, *O. taurus* dominated the fauna during the spring and summer, but was replaced by *A. lividus* during the autumn as the most dominant species. The Aphodiinae were the dominant group at all sites during the winter. *Aphodius distinctus* comprised the largest percentage of beetles trapped from Goldsboro, while *A. granarius* dominated the fauna in Salisbury. However, only 14 beetles were trapped from Salisbury during the winter making it difficult to characterize species dominance.

**Discussion**

Factors that influence the distribution, dispersal and health of dung beetle populations involve pesticide use history, soil type, moisture, and species specific climate requirement (Halffter and Matthews 1966, Fincher 1973, Blume et al. 1976, Nealis 1977, Hanski and Cambefort 1991, Barkhouse and Ridsill-Smith 1986, Fincher 1991, Dadour et al. 1999). I suspect the extreme disparity in species richness and the number of trapped beetles, between Salisbury and Goldsboro, is likely due to soil texture more than any other factor. Both sites had similar vegetative ground cover, animal feed and weather
patterns, yet only half as many species were taken from Salisbury (Table 3). In addition, the Salisbury site yielded only about 14 and 7% of the beetles trapped from the Goldsboro beef and dairy units, respectively. This is congruent with Nealis’ (1977) findings that clay soils lack the high species richness (total number of species) and high beetle numbers of sandier soils. He speculated that clay soils were difficult to tunnel in, and thus reduced the amount of brood a female can produce, leading to smaller population sizes.

In addition to site differences in our study there were extreme differences between the trapping years. For example, from May through September of 2002, 2,856 beetles were trapped from Salisbury, 23,196 beetles were trapped from the Goldsboro dairy unit and 14,205 beetles were trapped from the beef unit. During the same time in 2003, 89% fewer (312) beetles were trapped from Salisbury. Similarly, there was a 73% (3,823) decline in the number of beetles caught at the CEFS beef unit during the same trapping period. In contrast, the number of beetles caught at the CEFS diary increased to 27,503 beetles during the same trapping period. Conditions remained fairly constant between the years, with the exception of precipitation. During that time frame, rainfall more than doubled during 2003 (Figures 5 and 6). Salisbury received 26.47 cm of rain during 2002 and 68.83 cm during the same time in 2003. Goldsboro had similar amounts of precipitation; 36.14 cm fell in 2002 and 69.37 cm fell in 2003. Rainfall may be a limiting factor especially in clay rich soils. Fincher (1973) observed that increased desiccation negatively affected brood survival in sandy soils. While this may be true in some areas, Nealis (1977) noted that sandy soils drain better and may have a higher water table than those in his experiment. In contrast, clay soils hold more water and saturation occurs
more rapidly. If the soil is saturated, brood may suffocate due to the lack of oxygen exchange. Nealis (1977) also surmised that heavy rains rarely saturate clay soils thoroughly. However, he did not take into account that beetles tend to bury dung more shallowly in clay soils than in sandy soils (Halffter and Matthews 1966, Fincher 1973). If excessive rainfall was a mortality factor in clay soil it would explain the difference in beetle numbers between years at Salisbury and the beef unit at Goldsboro (which seemed to have a higher clay content than the dairy unit). In light of this information cultural practices, such as aerating clay soils, may prove beneficial to dung beetle diversity and population size. Further investigations are needed to determine whether this is true.

The domination of these sites by exotic dung beetle species is not surprising. In the past, several *Onthophagus* and *Aphodius* species have been introduced and spread over much of North America. They are now the dominant species in pastures where they are found. *Onthophagus nuchicornis* (L.) was introduced into North America from Europe prior to the 1840’s (Hoebeke and Beucke 1997). It is now the most dominant dung beetle trapped in Alberta, Canada (Floate 1998).

*Onthophagus gazella* was introduced for pasture improvement into Texas (and subsequently into California, Arkansas, Georgia and Mississippi) beginning in the early 1970’s (Blume and Aga 1978, Hoebeke and Beucke 1997). This species is a common beetle in much of the southern U.S. and has dominated the dung beetle fauna in areas of Texas during recent years (Howden and Scholtz 1986). Although *O. gazella* was introduced into New Jersey, it has not been recovered (Hoebeke and Beucke 1997). The previously known northern range of this species was Tennessee, southwestern Kansas and southeastern Missouri (Macrae and Penn 2001). *Onthophagus gazella* was found
abundantly in North Carolina during this study and represents the most northern record of this species on the Atlantic coast. Though only found abundantly in the coastal plain region of the state (no specimens were collected from Salisbury in the piedmont region), specimens were taken in Nashville, NC (Nash Co.) during the summer of 2003. This area is transitional between the sandy loam, coastal plain soils and the clay soils of the piedmont region. This suggests that *O. gazella* may become established in the western (piedmont) part of the state in the future. The northern movement of this beetle may be hampered by the shorter season of activity in areas that do not achieve high temperatures for a long enough period in the summer and autumn. The seasonal activity of *O. gazella* in this study was short, with beetles only present from May through November, and peak activity occurring from August to October. It is doubtful that this species will become established in more northern areas.

*Onthophagus taurus* was the most abundant beetle in this study, comprising from 45.40% (Goldsboro beef unit) to 73.35% (Goldsboro dairy unit) of the total population. This exotic beetle is a medium size tunneler, with a relatively high fecundity (pairs produce an average of 23 brood masses per two weeks) (Hunt and Simmons 2002). *Onthophagus taurus* was initially found during the early 1970’s, in the Florida panhandle (Fincher and Woodruff 1975). It has since migrated as far North as New York (Hoebek and Beucke 1997). *Onthophagus gazella* would likely be as abundant as *O. taurus* in these pastures, due to its higher fecundity, except that *O. gazella* is only present in high numbers for a short period of the year (Blume and Aga 1975) (Figure 9).

Seven imported *Aphodius* species, *A. distinctus*, *A. erraticus*, *A. fimetarius*, *A. granarius*, *A. haemorrhoidalis*, *A. lividus* and *A. prodromus* and two native species, *A.
*campestris* and *A. rubeolus*, are all generalist dung beetles, with a preference for open pastures and bovine dung (Gordon 1983). Four other native *Aphodius* collected in this study, *A. bicolor, A. stupidus, A. lutulentus* and *A. rusicola*, demonstrate a preference for deer dung. Interestingly, no native *Aphodius* were trapped from Salisbury and only 0.63% of the *Aphodius* trapped from Goldsboro were native, indicating that these species indeed do not readily utilize cattle dung (Table 3).

Howden and Scholtz (1986) stated that no more than five or six species of dung beetles should individually represent more than 5% of total dung beetle community in any given area. Overall this held true during the study and during each season (Tables 4-7). Three species, *O. taurus, A lividus* and *A. erraticus*, held dominance (ranked respectively) at both the Goldsboro and Salisbury dairies. Four species (*O. taurus, A. lividus, O. gazella* and *O. pennsylvanicus*) dominated the Goldsboro beef unit throughout the study.

The studies presented herein provide information about dung beetle assemblages in areas that transition from North temperate regions to South temperate/subtropical regions in North America. Nineteen of the species collected (in the Aphodiinae and Geotrupidae) are major species making up North temperate assemblages. The remaining 11 species (the Scarabaeinae and Coprinae) represent diversity more characteristic of southern regions.

Many of the beetles found in this study are widely distributed across North America. Across their ranges, differences in abiotic characteristics, particularly temperature and precipitation, of areas where these species occur can effect changes in their seasonal activity.
*Aphodius distinctus* is mainly a winter species in North Carolina. Individuals were taken from late November through the middle of January in this study, and even into March. Davis saw this same pattern for *A. distinctus* in North Carolina during 1956-57 (Davis 1966). Observations on the activity of this species in Canada showed that it was present during the autumn, specifically from September through October (Floate 1998). This shift is logical considering the colder climate in Canada as compared to North Carolina. As in Canada, this species occurs during October in the Netherlands (Europe) (Heijerman 1990).

*Aphodius granarius* had a short period of activity, February through April, in North Carolina during the mid 1950’s (Davis 1966). Though this species still had a short period of activity during this study, activity was consistent from early March through early May. This shift is most likely negligible and is probably due to slight climate differences between the studies. However, the seasonal distribution of *A. granarius* in Canada reflects a much colder climate, where temperatures do not consistently break freezing until late March and Early April (Floate 1998). Under these conditions, *A. granarius* does not become active until May, with activity ceasing in the middle of August. The short, three-month period is maintained in this area, but is shifted relative to climatic conditions. This species is considered a summer species in the Netherlands (Heijerman 1990).

The seasonal activity of *Aphodius lividus*, *Onthophagus gazella* and *Onthophagus pennsylvanicus* trapped herein were similar to those trapped in Texas (Fincher et al. 1986). These beetles are active for long periods of the year, usually from March through November. Because of the wide-ranging temperatures during these months these species
seem to be less affected by these temperatures, displaying similar seasonal activity over much of their range.

This study represents the first report of two species previously unknown to North Carolina, *Onthophagus gazella* and *Aphodius prodromus* (Phillip Harpootlian, pers. comm.). Currently, *O. gazella* appears to be regionally limited to eastern North Carolina, while *A. prodromus* seems restricted to the piedmont. The data collected during this study are valuable in judging future ecological shifts in the distribution and seasonal activity of these dung beetles as well as their species composition and richness. Future introductions of exotic species, for the control of dung, will likely depend on their seasonal activity and impact on existing species. In the past, baseline data were lacking; this study provides an overview of the dung beetle species existing in the cattle pastures in the Piedmont region and Coastal Plain region, of North Carolina.
Acknowledgements

I would like to thank Steve Denning and Rick Santangelo for their technical support on this project, and Dr. Cavell Brownie for her statistical assistance. I would also like to thank Andy Meier, Eddie Pitzer and Earl Toler (CEFS) and Correll Hall (Piedmont Research Station) for their help at the research sites. This project could not have been accomplished without the generous funding of Southern Regional IPM (grant # NC 09101).
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40: 313-316.


adult Coleoptera recovered from cattle and sheep manure in east central South

967.

Macrae, T. C., and S. R. Penn. 2001. Additional records of adventive *Onthophagus*

(NCDA & CS) North Carolina Department of Agriculture and Consumer Services,
CS, Raleigh, NC. (http://www.ncagr.com/stats/index.htm)

Nealis, V. G. 1977. Habitat association and community analysis of South Texas dung

(SCO) State Climate Office of North Carolina. 2003. SCO, Raleigh, NC.

(http://www.nc-climate.ncsu.edu/)


Table 1. Chi-square ($\chi^2$) values calculated for trap catch distributions during 2002 [critical $\chi^2$ value = 15.5 (at $\alpha = 0.05$)].

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* Significant at the $\alpha = 0.05$ level

$^a$ Observed trap totals for each of ten traps

$^b$ Expected frequency = (Obs. Total / 10 traps)

$^c$ $\chi^2 = (\text{Obs.} - \text{Exp.})^2 / \text{Exp.}$
Table 2. Chi-square ($\chi^2$) values calculated for trap catch distributions during 2003 [critical $\chi^2$ value = 15.5 (at $\alpha = 0.05$)].

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<tbody>
<tr>
<td></td>
<td>Obs.$^a$</td>
<td>Exp.$^b$</td>
</tr>
<tr>
<td>148</td>
<td>392.1</td>
<td>151.96</td>
</tr>
<tr>
<td>520</td>
<td>392.1</td>
<td>41.72</td>
</tr>
<tr>
<td>180</td>
<td>392.1</td>
<td>114.73</td>
</tr>
<tr>
<td>666</td>
<td>392.1</td>
<td>191.33</td>
</tr>
<tr>
<td>629</td>
<td>392.1</td>
<td>143.13</td>
</tr>
<tr>
<td>618</td>
<td>392.1</td>
<td>130.15</td>
</tr>
<tr>
<td>213</td>
<td>392.1</td>
<td>81.81</td>
</tr>
<tr>
<td>225</td>
<td>392.1</td>
<td>71.21</td>
</tr>
<tr>
<td>338</td>
<td>392.1</td>
<td>7.46</td>
</tr>
<tr>
<td>384</td>
<td>392.1</td>
<td>0.17</td>
</tr>
<tr>
<td>Total</td>
<td>3921</td>
<td>3921</td>
</tr>
</tbody>
</table>

$^a$ Observed trap totals for each of ten traps

$^b$ Expected frequency = (Obs. Total / 10 traps)

$^c$ $\chi^2$ = (Obs. – Exp.)$^2$ / Exp.
Table 3. Species and number of dung beetles trapped from Goldsboro (Center for Environmental Farming Systems) and Salisbury (Piedmont Research Station), NC during the study (March 2002 – September 2003).

<table>
<thead>
<tr>
<th>Species</th>
<th>Goldsboro Dairy Unit</th>
<th>Goldsboro Beef Unit</th>
<th>Salisbury Dairy Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. of beetles (%)</td>
<td>No. of beetles (%)</td>
<td>No. of beetles (%)</td>
</tr>
<tr>
<td><strong>Aphodius bicolor</strong></td>
<td>25 (0.04)</td>
<td>26 (0.09)</td>
<td>-</td>
</tr>
<tr>
<td>A. campestris</td>
<td>22 (0.04)</td>
<td>29 (0.10)</td>
<td>-</td>
</tr>
<tr>
<td>A. distinctus</td>
<td>188 (0.33)</td>
<td>657 (2.28)</td>
<td>1 (0.02)</td>
</tr>
<tr>
<td>A. erraticus</td>
<td>3,419 (6.00)</td>
<td>1,336 (4.63)</td>
<td>225 (5.47)</td>
</tr>
<tr>
<td>A. fimetarius</td>
<td>81 (0.14)</td>
<td>90 (0.31)</td>
<td>13 (0.32)</td>
</tr>
<tr>
<td>A. granarius</td>
<td>15 (0.03)</td>
<td>72 (0.25)</td>
<td>103 (2.51)</td>
</tr>
<tr>
<td>A. haemorrhoidalis</td>
<td>-</td>
<td>-</td>
<td>6 (0.15)</td>
</tr>
<tr>
<td>A. lividus</td>
<td>6,857 (12.02)</td>
<td>8,938 (30.97)</td>
<td>776 (18.88)</td>
</tr>
<tr>
<td>A. lutulentus</td>
<td>4 (0.01)</td>
<td>15 (0.05)</td>
<td>-</td>
</tr>
<tr>
<td>A. prodromus</td>
<td>-</td>
<td>-</td>
<td>12 (0.29)</td>
</tr>
<tr>
<td>A. rubeolus</td>
<td>9 (0.02)</td>
<td>1 (&lt;0.01)</td>
<td>-</td>
</tr>
<tr>
<td>A. rusicola</td>
<td>4 (0.01)</td>
<td>1 (&lt;0.01)</td>
<td>-</td>
</tr>
<tr>
<td>A. stupidus</td>
<td>1 (&lt;0.01)</td>
<td>1 (&lt;0.01)</td>
<td>-</td>
</tr>
<tr>
<td><strong>Ataenius erratus</strong></td>
<td>10 (0.02)</td>
<td>61 (0.21)</td>
<td>-</td>
</tr>
<tr>
<td>A. imbricatus</td>
<td>2 (&lt;0.01)</td>
<td>2 (0.01)</td>
<td>-</td>
</tr>
<tr>
<td>A. miainii</td>
<td>-</td>
<td>1 (&lt;0.01)</td>
<td>-</td>
</tr>
<tr>
<td>A. platensis</td>
<td>50 (0.09)</td>
<td>87 (0.30)</td>
<td>14 (0.34)</td>
</tr>
<tr>
<td>A. simulator</td>
<td>1 (&lt;0.01)</td>
<td>2 (0.01)</td>
<td>-</td>
</tr>
<tr>
<td><strong>Canthon pilularius</strong></td>
<td>3 (0.01)</td>
<td>5 (0.02)</td>
<td>-</td>
</tr>
<tr>
<td>C. vigilans</td>
<td>2 (&lt;0.01)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Copris minutus</strong></td>
<td>2 (&lt;0.01)</td>
<td>2 (0.01)</td>
<td>1 (0.02)</td>
</tr>
<tr>
<td><strong>Dichotomius carolinus</strong></td>
<td>4 (0.01)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Geotrupes b. blackburnii</strong></td>
<td>98 (0.17)</td>
<td>97 (0.34)</td>
<td>1 (0.02)</td>
</tr>
<tr>
<td><strong>Onthophagus gazella</strong></td>
<td>2,040 (3.58)</td>
<td>1,927 (6.68)</td>
<td>-</td>
</tr>
<tr>
<td>O. h. hecate</td>
<td>530 (0.93)</td>
<td>354 (1.23)</td>
<td>87 (2.12)</td>
</tr>
<tr>
<td>O. oklahomensis</td>
<td>16 (0.03)</td>
<td>1 (&lt;0.01)</td>
<td>-</td>
</tr>
<tr>
<td>O. pennsylvanicus</td>
<td>1,699 (2.98)</td>
<td>1,896 (6.57)</td>
<td>140 (3.41)</td>
</tr>
<tr>
<td>O. taurus</td>
<td>41,829 (73.35)</td>
<td>13,100 (45.40)</td>
<td>2,729 (66.38)</td>
</tr>
<tr>
<td>O. tuberculifrons</td>
<td>14 (0.02)</td>
<td>41 (0.14)</td>
<td>-</td>
</tr>
<tr>
<td><strong>Phanaeus vindex</strong></td>
<td>100 (0.18)</td>
<td>115 (0.40)</td>
<td>3 (0.07)</td>
</tr>
</tbody>
</table>

**TOTAL** 57,025 28,857 4,111

n = 10 traps for each unit

* Accidentally introduced species (Fincher and Woodruff 1975, Gordon 1983)

* Intentionally introduced species (Blume and Aga 1978)

* New state records for North Carolina
Table 4. Mean percent species composition of dung beetles collected during the winter (21 December through 20 March) from each site.

<table>
<thead>
<tr>
<th>Species</th>
<th>Dairy Unit&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Goldsboro</th>
<th>Beef Unit&lt;sup&gt;b&lt;/sup&gt;</th>
<th>%</th>
<th>Salisbury</th>
<th>Dairy Unit&lt;sup&gt;c&lt;/sup&gt;</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. distinctus</td>
<td>52.27</td>
<td>A. distinctus</td>
<td>46.56</td>
<td></td>
<td>A. granarius</td>
<td>52.22</td>
<td></td>
</tr>
<tr>
<td>A. erraticus</td>
<td>15.19</td>
<td>A. granarius</td>
<td>26.68</td>
<td></td>
<td>A. prodromus</td>
<td>20.00</td>
<td></td>
</tr>
<tr>
<td>A. lividus</td>
<td>11.11</td>
<td>A. lividus</td>
<td>16.59</td>
<td></td>
<td>A. lividus</td>
<td>11.11</td>
<td></td>
</tr>
<tr>
<td>O. taurus</td>
<td>6.67</td>
<td>G. b. blackburnii</td>
<td>3.03</td>
<td></td>
<td>O. h. hecate</td>
<td>11.11</td>
<td></td>
</tr>
<tr>
<td>A. granarius</td>
<td>4.06</td>
<td>O. tuberculifrons</td>
<td>1.89</td>
<td></td>
<td>O. taurus</td>
<td>5.56</td>
<td></td>
</tr>
<tr>
<td>G. b. blackburnii</td>
<td>4.06</td>
<td>A. bicolor</td>
<td>1.33</td>
<td></td>
<td>Other</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>A. lutulentus</td>
<td>2.02</td>
<td>A. erraticus</td>
<td>1.32</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A. fimetarius</td>
<td>1.85</td>
<td>Other</td>
<td>2.60</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O. h. hecate</td>
<td>1.48</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>1.29</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup> Mean percentages based on 226 beetles total  
<sup>b</sup> Mean percentages based on 527 beetles total  
<sup>c</sup> Mean percentages based on 14 beetles total
Table 5. Mean percent species composition of dung beetles collected during the spring (21 March through 20 June) from each site.

<table>
<thead>
<tr>
<th>Species</th>
<th>Goldsboro</th>
<th>Species</th>
<th></th>
<th>Salisbury</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dairy Unit(^a)</td>
<td>%</td>
<td>Beef Unit(^b)</td>
<td>%</td>
<td>Dairy Unit(^c)</td>
</tr>
<tr>
<td>O. taurus</td>
<td>65.79</td>
<td>O. taurus</td>
<td>46.58</td>
<td>O. taurus</td>
<td>43.54</td>
</tr>
<tr>
<td>A. erraticus</td>
<td>14.44</td>
<td>A. lividus</td>
<td>32.09</td>
<td>A. erraticus</td>
<td>19.72</td>
</tr>
<tr>
<td>A. lividus</td>
<td>13.04</td>
<td>A. erraticus</td>
<td>10.41</td>
<td>O. h. hecate</td>
<td>9.71</td>
</tr>
<tr>
<td>O. pennsylvanicus</td>
<td>4.87</td>
<td>O. pennsylvanicus</td>
<td>6.72</td>
<td>A. granarius</td>
<td>9.34</td>
</tr>
<tr>
<td>Other</td>
<td>1.86</td>
<td>O. h. hecate</td>
<td>1.36</td>
<td>O. pennsylvanicus</td>
<td>9.32</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other</td>
<td>2.83</td>
<td>A. lividus</td>
<td>5.31</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>A. prodromus</td>
<td>1.59</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Other</td>
<td>1.47</td>
</tr>
</tbody>
</table>

\(^a\) Mean percentages based on 26,086 beetles total
\(^b\) Mean percentages based on 12,713 beetles total
\(^c\) Mean percentages based on 999 beetles total
Table 6. Mean percent species composition of dung beetles collected during the summer (21 June through 20 September) from each site.

<table>
<thead>
<tr>
<th>Dairy Unit&lt;sup&gt;a&lt;/sup&gt; Species</th>
<th>Goldsboro Species</th>
<th>%</th>
<th>Beef Unit&lt;sup&gt;b&lt;/sup&gt; Species</th>
<th>%</th>
<th>Salisbury Dairy Unit&lt;sup&gt;c&lt;/sup&gt; Species</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>O. taurus</td>
<td>O. taurus</td>
<td>72.75</td>
<td>O. taurus</td>
<td>54.05</td>
<td>O. taurus</td>
<td>64.73</td>
</tr>
<tr>
<td>A. lividus</td>
<td>A. lividus</td>
<td>14.31</td>
<td>A. lividus</td>
<td>19.60</td>
<td>A. lividus</td>
<td>23.20</td>
</tr>
<tr>
<td>O. gazella</td>
<td>O. pennsylvanicus</td>
<td>7.45</td>
<td>O. pennsylvanicus</td>
<td>16.39</td>
<td>O. h. hecate</td>
<td>4.81</td>
</tr>
<tr>
<td>O. pennsylvanicus</td>
<td>O. h. hecate</td>
<td>3.25</td>
<td>O. h. hecate</td>
<td>5.14</td>
<td>O. pennsylvanicus</td>
<td>3.70</td>
</tr>
<tr>
<td>O. h. hecate</td>
<td>O. gazella</td>
<td>1.67</td>
<td>O. gazella</td>
<td>2.65</td>
<td>A. platensis</td>
<td>2.39</td>
</tr>
<tr>
<td>Other</td>
<td>P. vindex</td>
<td>0.57</td>
<td>Other</td>
<td>1.02</td>
<td>Other</td>
<td>1.18</td>
</tr>
<tr>
<td>Other</td>
<td>Other</td>
<td>0.57</td>
<td>Other</td>
<td>1.15</td>
<td>Other</td>
<td>1.18</td>
</tr>
</tbody>
</table>

<sup>a</sup> Mean percentages based on 26,306 beetles total  
<sup>b</sup> Mean percentages based on 5,733 beetles total  
<sup>c</sup> Mean percentages based on 436 beetles total
Table 7. Mean percent species composition of dung beetles collected during the autumn (21 September through 20 December) from each site.

<table>
<thead>
<tr>
<th>Dairy Unit&lt;sup&gt;a&lt;/sup&gt; Species</th>
<th>Goldsboro %</th>
<th>Beef Unit&lt;sup&gt;b&lt;/sup&gt; Species</th>
<th>%</th>
<th>Salisbury Dairy Unit&lt;sup&gt;c&lt;/sup&gt; Species</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>O. taurus</td>
<td>55.53</td>
<td>A. lividus</td>
<td>38.33</td>
<td>O. taurus</td>
<td>62.72</td>
</tr>
<tr>
<td>A. lividus</td>
<td>26.21</td>
<td>O. taurus</td>
<td>34.72</td>
<td>A. lividus</td>
<td>29.58</td>
</tr>
<tr>
<td>O. gazella</td>
<td>7.33</td>
<td>O. gazella</td>
<td>14.95</td>
<td>O. pennsylvanicus</td>
<td>3.01</td>
</tr>
<tr>
<td>O. pennsylvanicus</td>
<td>2.93</td>
<td>O. pennsylvanicus</td>
<td>3.83</td>
<td>O. h. hecate</td>
<td>2.94</td>
</tr>
<tr>
<td>O. h. hecate</td>
<td>2.31</td>
<td>P. vindex</td>
<td>2.13</td>
<td>A. platensis</td>
<td>1.47</td>
</tr>
<tr>
<td>A. distinctus</td>
<td>1.81</td>
<td>A. distinctus</td>
<td>1.72</td>
<td>Other</td>
<td>0.28</td>
</tr>
<tr>
<td>G. b. blackburnii</td>
<td>1.68</td>
<td>O. h. hecate</td>
<td>1.46</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>2.20</td>
<td>A. platensis</td>
<td>1.39</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other</td>
<td>1.46</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup> Mean percentages based on 2,950 beetles total
<sup>b</sup> Mean percentages based on 8,436 beetles total
<sup>c</sup> Mean percentages based on 754 beetles total
Figure 1. Diagram of the dung-baited pitfall trap used in this study. A frozen bait containing cattle dung (A) was placed on an elevated grate above a funnel (B) which in turn was attached to a canister with a screen bottom (C).
Figure 2. Map of the dairy unit at the Piedmont Research Station, Salisbury, NC. Traps positions are represented by dots and were maintained from 9 March 2002 through 26 September 2003. Cattle were rotated during the year throughout the farm with animals constantly on pasture D9. [T = trees; * = barn and milking parlor]
Figure 3. Map of the beef unit at CEFS, Goldsboro, NC. The trap locations represented by an \( \times \) were maintained from 7 March 2002 through 4 June 2002. The 22 possible trap locations from 19 June 2002 through 25 September 2003 are represented by dots. Cattle were rotated throughout the unit, but were most often placed on pastures 19, 18 (A-G) and 20 (A-E).
Figure 4. Map of the dairy unit at CEFS, Goldsboro, NC. The trap locations represented by dots were maintained from 7 March 2002 through 4 June 2002. The 36 possible trap locations from 19 June 2002 through 7 March 2003 are represented by an x. The 13 possible trap locations from 25 March 2003 through 25 September 2003 are represented by triangles. The acreage (ac) of some pastures is given to show relative size. [* = open milking parlor]
Figure 5. Mean temperature (with maximum and minimum bars) and accumulated precipitation* for Salisbury during the study (top) and total beetles trapped throughout the study (bottom). [* = accumulation between trapping dates]
Figure 6. Mean temperature (with maximum and minimum bars) and accumulated precipitation* for Goldsboro during the study† (top) and total beetles trapped throughout the study (bottom; solid line = dairy unit; dashed line = beef unit). [* = accumulation between trapping dates; † = no data available until May 7, 2002]
Figure 7. Seasonal activity of *Onthophagus taurus* in Salisbury (top) and Goldsboro (bottom). [solid line = dairy unit; dashed line = beef unit]
Figure 8. Seasonal activity of *Aphodius lividus* in Salisbury (top) and Goldsboro (bottom). [solid line = dairy unit; dashed line = beef unit]
Figure 9. Seasonal activity of *Aphodius erraticus* in Salisbury (top) and Goldsboro (bottom). [solid line = dairy unit; dashed line = beef unit]
Figure 10. Seasonal activity of *Onthophagus gazella* in Goldsboro*.
[solid line = dairy unit; dashed line = beef unit]
* No *O. gazella* were taken from Salisbury
Figure 11. Seasonal activity of *Onthophagus pennsylvanicus* in Salisbury (top) and Goldsboro (bottom). [solid line = dairy unit; dashed line = beef unit]
Figure 12. Seasonal activity of *Aphodius granarius* in Salisbury (top) and Goldsboro (bottom). [solid line = dairy unit; dashed line = beef unit]
Figure 13. Seasonal activity of *Aphodius distinctus* in Goldsboro*. [solid line = dairy unit; dashed line = beef unit]

* One *A. distinctus* was trapped in Salisbury on November 8th, 2002.
Figure 14. Seasonal activity of *Onthophagus hecate hecate* in Salisbury (top) and Goldsboro (bottom). [solid line = dairy unit; dashed line = beef unit]
III. The role of *Onthophagus taurus* and *Onthophagus gazella* (Coleoptera: Scarabaeidae) in pasture soil nutrition

Abstract

The effect of dung beetle activity on soil nutrition was studied in three distinct soil types under laboratory conditions. Two paracoprid dung beetles, *Onthophagus gazella* (Fabricius) and *Onthophagus taurus* Schreber, were allowed to incorporate dung, for brood production, into a piedmont Cecil clay soil, a coastal plain sandy-loam soil and washed sand. Soils were also exposed to dung alone to compare the effects of dung left on the soil surface. Beetles produced the most brood in the clay soil, with *O. gazella* producing an average of 92.0 ± 11.6 total brood per 8 breeding pairs and *O. taurus* producing an average of 55.3 ± 7.7 total brood per 8 breeding pairs. This study demonstrates an increase in primary and secondary nutrients, an increase in soil pH and an increase in the cation exchange capacity of soils in response to dung beetle activity.

**Keywords:** *Onthophagus taurus, Onthophagus gazella,* soil nutrition

During the last century the United States experienced the arrival of *Onthophagus taurus* and *Onthophagus gazella*. The European beetle *Onthophagus taurus* was accidentally introduced from an unknown location into Florida circa 1971 (Fincher and Woodruff 1975). *Onthophagus gazella* was imported from Africa (via Australia) into Texas in 1970 for pasture improvement (Blume and Aga 1978). Since their introduction, populations have spread over much of the southeastern U.S. (Fincher et al. 1983, Hunter and Fincher 1985, Macrae and Penn 2001). Recently both species were found to be abundant in cattle pastures in North Carolina (Chapter II).

*Onthophagus taurus* and *O. gazella* are of particular interest because of their ability to bury large amounts of manure. *Onthophagus taurus* measures 8-10 mm in length and constructs brood masses weighing an average of 1.6 g (Hunt and Simmons 2002). A pair of these beetles can produce an average of 23 brood masses in a two-week
time period (equaling about 36.8 g of dung buried per pair per two weeks) (Hunt and Simmons 2002). Considered the most fecund of dung beetle species, *Onthophagus gazella* is a larger species (10-13 mm) producing an average of 90 offspring per female (Blume and Aga 1975, Hoebeke and Beucke 1997). These beetles bury around 4-5 cc of dung, which is compacted into a brood mass measuring 2 cc (Bornemissza 1970). Theoretically, a pair of *O. gazella* could bury an average of 180 cc of dung in their adult lifespan of around 60 days. In addition to fecundity and size, the abundance of a dung beetle species in an area contributes to the total amount of dung buried (Mittal 1993).

Both *Onthophagus taurus* and *O. gazella* inhabit North Carolina cattle pastures and contribute to dung burial. Presumably their activity improves soil nutrition. The object of this study was to quantify the amount of nutrient change in soils of different types (piedmont clay, coastal plain sandy-loam and sand) caused by the burial activities of these two species.

**Materials and Methods**

**Soils.** Coastal plain, sandy-loam soil was collected from the Center for Environmental Farming Systems (CEFS), in Goldsboro, NC. Piedmont Cecil clay soil was collected from North Carolina State University’s Lake Wheeler Road Field Laboratory in Raleigh, NC. Washed sand, purchased from a local home improvements store, was selected as a nutrient deficient substrate for comparison. Nine, 8 L plastic planting pots (23 cm in diameter x 23.5 cm deep) were filled with 6.5 L (19 cm) of each soil type. Water was added to the play sand to simulate natural moisture found in the other soil types (10% by weight). Soils were tamped to increase density and frozen in a
chest freezer (-18°C) for 4 days to kill any insects. The pots were allowed to thaw and equilibrate to a controlled temperature (28°C) before use.

**Brood Production.** Dung beetles were caught from a wild population at CEFS in Goldsboro, NC. Beetles were caught using dung-baited pitfall traps and a black light trap (attractive to *O. gazella*). Collected beetles were brought to the laboratory and all *O. gazella* and *O. taurus* were separated by species and gender from other species.

Fresh dung was collected from pesticide-free dairy cattle fed on pasture and silage at the CEFS farm. The dung was then frozen to -18°C to kill any insects feeding on it, including other dung beetles. Once thawed, the dung was homogenized by hand and added to each treatment pot in 550g aliquots. Pots containing each soil type received a dung only treatment, 16 *O. gazella* (8 male and female pairs) or 16 *O. taurus* (8 pairs). To measure pre-treatment nutrient levels pots containing each soil type were left untreated. Each treatment was replicated three times in each soil type. All pots were kept in a controlled room (50% RH; 28°C; 12/12 photoperiod) for the duration of the experiment. Beetles were allowed an initial 4 days to incorporate dung. After the initial 4 days all unincorporated dung remaining on the surface was removed, and an additional aliquot of 550 g of fresh dung was added. The beetles were allowed an additional 4 days to incorporate the second portion of dung.

After 8 days of activity, adult beetles were trapped and removed using small pitfall traps baited with dung. Offspring were given 30 days to develop and emerge. Teneral adults were removed and counted. Each pot was then emptied onto a clean surface and the soil carefully examined for brood balls. Each brood ball was evaluated to determine lifestage of the beetle or classified as brood masses without development. All
soil, brood masses, dead adults and pupation chambers were processed through a 2mm sieve. Soil from each pot was then homogenized for 5 minutes in a large (90 kg) capacity grain mixer.

Soil Analysis. Homogenized soil from each pot was sub-sampled by collecting three, 300 cc samples. These samples were analyzed for nutrient content by the NC soil test laboratory, North Carolina Department of Agriculture & Consumer Services (NCDA & CS). A Mehlich-3 extractant was used to analyze primary nutrients (potassium and phosphorus), secondary nutrients (calcium and magnesium) and micronutrients (manganese, copper and zinc) (Mehlich 1984a). Nitrogen was not included in the soil test because of its unstable nature. Bovine dung contains about 1% nitrogen with about 10% of that lost to volatilization (Behling Miranda et al. 2000, Ferreira et al. 1995). The exchangeable acidity and humic matter of each soil were tested using Mehlich-buffer acidity and photometric determination, respectively (Mehlich et al. 1976, Mehlich 1984b). Cation exchange capacity (CEC) was calculated by the summation of the extractable potassium (K), magnesium (Mg), calcium (Ca) and the exchangeable acidity. Base saturation was calculated by dividing the sum of K, Mg and Ca into the CEC, resulting in a percentage of the CEC occupied by K, Mg and Ca.

Data Analysis. Data were analyzed using analysis of variance in SAS 8.2, including a contrast statement comparing the beetle treatments and non-beetle treatments (ANOVA, PROC GLM, SAS Institute 2001). Treatment comparisons were separated using Tukey’s Studentized Range Test ($\alpha = 0.05$).
Results and Discussion

**Brood Production.** Both *O. taurus* and *O. gazella* produced the most brood in the piedmont clay soil (Table 1). *Onthophagus gazella* averaged 92.0 ± 11.6 total brood in this soil type, while *O. taurus* averaged 55.3 ± 7.7. *Onthophagus taurus* produced the least amount of total brood (11.7 ± 1.8) in the sandy-loam soil. *Onthophagus gazella* produced no brood in the washed sand.

Dung beetle brood production is variable in the laboratory (Blume and Aga 1975, Fincher 1991). The average number of progeny for a female *Onthophagus gazella*, in a ten day period, is 16.5 (around one-and-a-half brood masses per day) (Blume and Aga 1975). Taking into account competition, 8 pairs of *O. gazella* occupying a single, 592 ml dung pat produced a total of 41 offspring (Lee and Peng 1982). The range of offspring produced by this species herein was from 0.0 ± 0.0 in the washed sand to 92.0 ± 11.6 in the piedmont clay. In contrast *O. taurus* was capable of reproducing in the washed sand. Fincher (1973) found that *Phanaeus* beetles had increased reproduction in soils with more clay content, and many failed to reproduce in construction site sand. *Onthophagus gazella* may reproduce similarly to *Phanaeus* in different soils. Like *Onthophagus gazella*, *Onthophagus taurus* produced variable numbers of offspring between soil types. Hunt and Simmons (2002) observed an average of 23 offspring per *O. taurus* pair in a 14 day period, which was higher than in the present study. However, in their study breeding pairs were isolated from one another, eliminating competition.

**Soil Analysis.** *Primary Nutrients.* Primary soil nutrients, including phosphorus (P) and potassium (K), are the most limiting and commonly deficient nutrients needed by
forage crops (Follett and Wilkinson 1995). Most fertilizers include various rates of P and K.

Phosphorus was significantly ($P < 0.05$) increased over all other treatments by $O. gazella$ in the piedmont soil (Table 2). The presence $Onthophagus taurus$ significantly increased P over the pre-treatment clay soil. Although $O. taurus$ nearly doubled the measured amounts of P ($14.96 \pm 1.49$), it was not significantly greater than the dung only treatment ($7.74 \pm 1.26$) (Table 2). There was no significant difference between beetle treatments and the dung treatment in the sandy-loam soil (Table 2). However, numerically the beetle treatments produced higher levels of P in the soil and there was a significant ($P < 0.0001$) contrast between beetle treatments and non-beetle treatments. Levels of P were significantly increased in the washed sand by both $O. gazella$ and $O. taurus$. Phosphorus levels were not statistically different in the pre-treatment and dung only pots (Table 2).

Potassium was significantly ($P < 0.05$) increased by $O. gazella$ in the piedmont soil, over all other treatments. $Onthophagus taurus$ did not increase K over the dung treatment in this soil type. The pre-treatment clay soil had the lowest levels of K of all other treatments (Table 2). In sandy-loam soil, both species of beetles significantly increased levels of K over the dung only and pre-treatment pots. Though lower than the beetle treatments, K levels were higher in the dung treatment than the pre-treatment (Table 2). Similar to the sandy-loam soil, the washed sand had significantly more K in the pots exposed to the beetles. Again, more K was detected in the dung only pots than the pre-treatment pots (Table 2).
Phosphorus serves many functions in forage crops. As an organic constituent, it makes up various enzymes, proteins, nucleic acids, phospholipids, esters and adenosine triphosphate (ATP) (Follett and Wilkinson 1995). It is responsible for enhanced plant cell division, lipid formation, bloom and seed formation, root development and may increase disease resistance (Follett and Wilkinson 1995). Potassium functions in the formation and translocation of sugars and starch, protein synthesis, stomatal function and winter-hardiness (Follett and Wilkinson 1995, Miller and Heichel 1995). Increases in both P and K were associated with beetle activity (Table 2). The increase in P seen in the dung only treatment in the sandy-loam soil may have been attributed to excess dung remaining on the soil surface before homogenization. Dung fragments in the soil contribute to N mineralization and may also contribute to increased P and K (Yokoyama et al. 1991). Consequently, though O. gazella did not produce any offspring in the sand, increases in the P and K content in this soil may be attributed to dung fragments buried for adult feeding.

Secondary Nutrients. Calcium (Ca) was only significantly increased by O. gazella over the pre-treatment in the clay soil (Table 2). Calcium levels were not different between the beetle treatments and the dung treatment. Levels of Ca in the sandy loam soil were highest in the pots exposed to O. gazella. The pots exposed to O. taurus were the next highest in Ca, followed by the dung treatment and, finally, lowest in the pre-treatment sandy-loam (Table 2). Washed sand exposed to O. taurus was highest in levels of Ca. Washed sand exposed to O. gazella was not significantly different from sand exposed to O. taurus or dung only, but was numerically higher in Ca than the dung alone.
and statistically ($P < 0.05$) higher than the pre-treatment. The dung treatment and pre-treatment levels of Ca were not statistically different (Table 2).

Magnesium (Mg) levels were highest in piedmont clay soils exposed to *O. gazella*. Levels of Mg from the clay soils did not differ between the *O. taurus* treatment and the dung treatment. However, all treatments increased the soil Mg above the pre-treatment. Both beetle species increased the amount of Mg in the sandy-loam soil above the pre-treatment. Pots exposed to *Onthophagus taurus* did not differ statistically from those exposed to dung alone, but were higher numerically. In the washed sand, Mg was present in the highest levels in pots exposed to *O. gazella* and *O. taurus*. The dung treatment was significantly higher than the pre-treatment, but lower than both beetle treatments.

Calcium (Ca pectate) is a major constituent of plant cell walls and also plays a part in intracellular organization (Follett and Wilkinson 1995, Miller and Heichel 1995). Magnesium is a constituent of chlorophyll and is a cofactor for enzymes involved in phosphorus and carbohydrate metabolism (Follett and Wilkinson 1995, Miller and Heichel 1995).

**Micronutrients.** In the presence of beetles, manganese (Mn) levels were elevated above pre-treatment levels in the sandy-loam soil, but not above the dung alone. Manganese levels in other soil types were not different between treatments.

Zinc (Zn) was increased in the pots containing sandy-loam soil, when beetles were present. Sandy-loam soil exposed to *O. gazella* contained higher levels of Zn than all but the *O. taurus* pots. *Onthophagus taurus* pots, however, did not differ from either the dung treatment or pre-treatment. Zinc was increased in the pots containing washed
sand exposed to beetles. However, the exposure of the washed sand to *O. taurus* did not differ statistically from that of the dung treatment (only numerically).

Copper (Cu) levels were not elevated over the dung treatment by exposure to beetles in any of the soils. Though micronutrients are needed in small amounts for various plant processes, in high concentrations they are toxic to forage plants (Follett and Wilkinson 1995, Miller and Heichel 1995).

Additional Soil Characteristics. The pH of the soils before treatment ranged from slightly acidic (5.55 ± 0.02) in the coastal plain soil to slightly basic (7.35 ± 0.04) in the piedmont clay (Table 3). The pH of the clay soil was not significantly different between all treatments (Table 3). An increase in pH was measured from both of the beetle treatments in the sandy-loam soil, although the *O. gazella* treatment was not significantly different from the pre-treatment. The pH of the sand varied the greatest between treatments, ranging from 6.15 ± 0.02 in the pre-treatment to 8.34 ± 0.07 in the *O. taurus* treatment. Both beetle treatments had a significantly higher pH (*P* < 0.05) than both the dung treatment and pre-treatment. The dung alone caused a significant (*P* < 0.05) increase in pH over the pre-treatment.

The exchangeable acidity was not significantly different between treatments in both the clay and sandy-loam soils, although the beetles treatments had numerically lower values (Table 3). The exchangeable acidity of the washed sand was reduced in the beetle treatments, significantly below the levels of both the dung only and pre-treatment.

The cation exchange capacity (CEC) of the clay soil was significantly increased over the dung only treatment and pre-treatment by the addition of *O. gazella*, but not *O. taurus* (Table 3). In the coastal plain sandy-loam soil, the CEC was increased by both
species over the pre-treatment. However, only *O. gazella* significantly increased the CEC above the dung only treatment in this soil. In the washed sand, *O. taurus* significantly increased the CEC over all of the treatments with the exception of the *O. gazella* treatment. There was no significant difference between the CEC of the *O. gazella* treatment and the dung only treatment, as well as between the dung only and the pre-treatment (Table 3).

The base saturation of the clay soil was not significantly different between treatments (Table 3). In both the sandy-loam soil and the washed sand the base saturation was significantly increased by beetle activity over both treatments without beetles. The base saturation was also higher in both soils in the dung only treatment than the pre-treatment.

Humic matter content was lowest in the pre-treatments of the clay soil and the sandy-loam soil (Table 3). All other treatments in these soils were not significantly different. In the washed sand, the humic matter content was lowest in both the pre-treatment and *O. taurus* treatment. The *O. gazella* treatment was not significantly different from the dung only treatment.

The CEC of each soil was increased by beetle activity, effectively increasing the ability of the soils to hold basic cations (including Ca, K and Mg). This, in conjunction with a lowering of the exchangeable acidity (numerically in the clay and sandy-loam soils, and significantly in the washed sand) and an increase in pH, results in an increase in the availability of beneficial nutrients and a decrease in the amount of toxic, soluble aluminum (Al).
In acid soils (pH < 5.5) the phytotoxic effects of Al is caused by the interruption of P, K, Ca, and Mg homeostasis resulting in the inhibition of cell division and root elongation (Rout et al. 2001, Cuenca et al. 2001). The restoration of acid soils to productivity may include the addition of lime, Ca or Mg. The addition of Ca in the form of gypsum increased productivity of mixed orchard grass and tall fescue 42% but decreased soil and plant Mg levels (Richey and Snuffer 2002). In soybeans, the addition of Mg in micromolar concentrations to Al toxic solutions was 100 fold more effective than Ca in overcoming Al toxicity and Mg may be acting at the root surface (Silva et al 2001). Dung beetles may mediate the effects of environmental stress through enhanced Ca, Mg, and K incorporation into soils. The relative importance of dung beetles in alleviating Al toxic effects would be limited to acid soils. Since soil pH for the piedmont clay was 7.35 ± 0.04, the possible benefits of dung beetle incorporation would be less than sandy loam soils with a pH of 5.55 ± 0.02.

Pasture grasses and legumes in North Carolina are subject to a range of abiotic stresses including drought, nutrient deprivation, and acidic soils/aluminum toxicity. Dung beetles have the potential to improve pastures through the incorporation of manure into pasture soils, increasing percolation and providing nutrients (Bornemissza 1960). Previous studies focused on the growth response of selected forage plants to dung beetle incorporated manure (Bornemissza and Williams 1970, Macqueen and Bierne 1975, Fincher et al. 1981, Kabir et al. 1985). In this study, I determined the benefits of two species of dung beetles, *O. gazella* and *O. taurus*, on soil quality under laboratory conditions. My study demonstrates an increase in primary and secondary nutrients, an
increase in soil pH and an increase in the cation exchange capacity of soils in response to
dung beetle burying activity.
Acknowledgements

I would like to thank Steve Denning, Rick Santangelo and Jennifer Keller for their assistance on this project. I would also like to thank Dr. David Hardy (NCDA & CS) for his help in facilitating the soil testing. This project was funded by a Southern Regional IPM grant.
References Cited


Table 1. Brood production (mean ± SEM) of *O. gazella* and *O. taurus* in different soil types

<table>
<thead>
<tr>
<th></th>
<th>Piedmont Mean ± SEM&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Coastal plain Mean ± SEM&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Washed sand Mean ± SEM&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>O. gazella</em>&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Larvae</td>
<td>0.3 ± 0.3</td>
<td>0.0 ± 0.0</td>
<td>0.0 ± 0.0</td>
</tr>
<tr>
<td>Pupae</td>
<td>1.3 ± 1.3</td>
<td>5.7 ± 4.7</td>
<td>0.0 ± 0.0</td>
</tr>
<tr>
<td>Adults</td>
<td>90.3 ± 12.7</td>
<td>20.3 ± 8.8</td>
<td>0.0 ± 0.0</td>
</tr>
<tr>
<td>Total Brood</td>
<td>92.0 ± 11.6</td>
<td>26.0 ± 4.6</td>
<td>0.0 ± 0.0</td>
</tr>
<tr>
<td><em>O. taurus</em>&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Larvae</td>
<td>0.0 ± 0.0</td>
<td>2.0 ± 0.0</td>
<td>11.3 ± 5.8&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Pupae</td>
<td>5.3 ± 1.5</td>
<td>3.7 ± 2.0</td>
<td>0.3 ± 0.3</td>
</tr>
<tr>
<td>Adults</td>
<td>50.0 ± 6.7</td>
<td>6.0 ± 3.0</td>
<td>2.0 ± 1.2</td>
</tr>
<tr>
<td>Total Brood</td>
<td>55.3 ± 7.7</td>
<td>11.7 ± 1.8</td>
<td>13.7 ± 5.3</td>
</tr>
</tbody>
</table>

<sup>a</sup> N = 3  
<sup>b</sup> Brood from 8 pairs of beetles  
<sup>c</sup> Includes brood with dead, early instars
Table 2. Nutrient levels (mean ± SEM) of each soil type before (pre-treatment) and after exposure to *O. gazella*, *O. taurus* or dung only.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>K</th>
<th>Mg</th>
<th>Ca</th>
<th>Sum Cations&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Piedmont</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dung + <em>O. gazella</em></td>
<td>0.39 ± 0.02&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.69 ± 0.06&lt;sup&gt;a&lt;/sup&gt;</td>
<td>8.17 ± 0.24&lt;sup&gt;a&lt;/sup&gt;</td>
<td>10.43 ± 0.27&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Dung + <em>O. taurus</em></td>
<td>0.27 ± 0.01&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.16 ± 0.02&lt;sup&gt;b&lt;/sup&gt;</td>
<td>6.82 ± 0.26&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>8.36 ± 0.29&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Dung only</td>
<td>0.23 ± 0.01&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.02 ± 0.02&lt;sup&gt;b&lt;/sup&gt;</td>
<td>7.00 ± 0.35&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>8.35 ± 0.37&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Pre-treatment</td>
<td>0.17 ± 0.00&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.83 ± 0.01&lt;sup&gt;c&lt;/sup&gt;</td>
<td>6.35 ± 0.17&lt;sup&gt;b&lt;/sup&gt;</td>
<td>7.54 ± 0.17&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Coastal plain</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dung + <em>O. gazella</em></td>
<td>0.25 ± 0.01&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.05 ± 0.03&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.94 ± 0.02&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.35 ± 0.05&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Dung + <em>O. taurus</em></td>
<td>0.23 ± 0.01&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.98 ± 0.04&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>1.74 ± 0.06&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.05 ± 0.11&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Dung only</td>
<td>0.18 ± 0.01&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.87 ± 0.03&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.49 ± 0.06&lt;sup&gt;c&lt;/sup&gt;</td>
<td>2.64 ± 0.09&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Pre-treatment</td>
<td>0.08 ± 0.00&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.53 ± 0.00&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.95 ± 0.01&lt;sup&gt;d&lt;/sup&gt;</td>
<td>1.65 ± 0.01&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Washed sand</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dung + <em>O. gazella</em></td>
<td>0.10 ± 0.01&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.27 ± 0.03&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.42 ± 0.05&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>0.90 ± 0.09&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Dung + <em>O. taurus</em></td>
<td>0.11 ± 0.01&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.28 ± 0.00&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.48 ± 0.00&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.97 ± 0.01&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Dung only</td>
<td>0.04 ± 0.00&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.15 ± 0.01&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.26 ± 0.05&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>0.45 ± 0.07&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Pre-treatment</td>
<td>0.01 ± 0.00&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.06 ± 0.01&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.16 ± 0.02&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.23 ± 0.02&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Different letters within columns and within soils indicate significant differences using Tukey’s Studentized Range Test (α = 0.05).

<sup>a</sup> The sum of the cations present in soil as tested.
Table 2. (continued) Nutrient levels (mean ± SEM) of each soil type before (pre-treatment) and after exposure to *O. gazella*, *O. taurus* or dung only.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>P</th>
<th>Mn</th>
<th>Zn</th>
<th>Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Piedmont</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dung + <em>O. gazella</em></td>
<td>47.72 ± 2.71a</td>
<td>76.97 ± 1.82a</td>
<td>8.45 ± 0.43a</td>
<td>5.72 ± 1.05a</td>
</tr>
<tr>
<td>Dung + <em>O. taurus</em></td>
<td>14.96 ± 1.49b</td>
<td>66.57 ± 1.95a</td>
<td>5.82 ± 0.40b</td>
<td>3.00 ± 0.27b</td>
</tr>
<tr>
<td>Dung only</td>
<td>7.54 ± 1.26bc</td>
<td>71.85 ± 4.59a</td>
<td>6.73 ± 0.80ab</td>
<td>3.26 ± 0.26ab</td>
</tr>
<tr>
<td>Pre-treatment</td>
<td>6.49 ± 1.29c</td>
<td>68.23 ± 2.70a</td>
<td>6.79 ± 0.24ab</td>
<td>3.37 ± 0.02ab</td>
</tr>
<tr>
<td><strong>Coastal plain</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dung + <em>O. gazella</em></td>
<td>204.57 ± 6.32a</td>
<td>1.91 ± 0.16a</td>
<td>2.04 ± 0.29a</td>
<td>0.39 ± 0.01a</td>
</tr>
<tr>
<td>Dung + <em>O. taurus</em></td>
<td>196.01 ± 10.66a</td>
<td>1.73 ± 0.12a</td>
<td>1.52 ± 0.13ab</td>
<td>0.37 ± 0.04ab</td>
</tr>
<tr>
<td>Dung only</td>
<td>174.73 ± 13.96a</td>
<td>1.58 ± 0.22ab</td>
<td>1.14 ± 0.22b</td>
<td>0.33 ± 0.04ab</td>
</tr>
<tr>
<td>Pre-treatment</td>
<td>99.4 ± 1.20b</td>
<td>0.98 ± 0.01b</td>
<td>0.88 ± 0.10b</td>
<td>0.26 ± 0.01b</td>
</tr>
<tr>
<td><strong>Washed sand</strong></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Dung + <em>O. gazella</em></td>
<td>24.66 ± 5.24a</td>
<td>0.92 ± 0.09a</td>
<td>1.82 ± 0.21a</td>
<td>0.12 ± 0.01a</td>
</tr>
<tr>
<td>Dung + <em>O. taurus</em></td>
<td>26.95 ± 1.44a</td>
<td>0.91 ± 0.02a</td>
<td>1.73 ± 0.04ab</td>
<td>0.24 ± 0.08a</td>
</tr>
<tr>
<td>Dung only</td>
<td>4.94 ± 0.25b</td>
<td>1.03 ± 0.55a</td>
<td>1.25 ± 0.02bc</td>
<td>0.05 ± 0.02a</td>
</tr>
<tr>
<td>Pre-treatment</td>
<td>3.10 ± 0.04b</td>
<td>0.43 ± 0.02a</td>
<td>1.05 ± 0.06c</td>
<td>0.08 ± 0.02a</td>
</tr>
</tbody>
</table>

Different letters within columns and within soils indicate significant differences using Tukey’s Studentized Range Test ($\alpha = 0.05$).
Table 3. Additional characteristics (mean ± SEM) of each soil type before (pre-treatment) and after exposure to *O. gazella*, *O. taurus* or dung only.

<table>
<thead>
<tr>
<th></th>
<th>pH</th>
<th>Exchangeable Acidity (meq/100 cm³)</th>
<th>Cation Exchange Capacity (meq/100 cm³)</th>
<th>Base Saturation (%)</th>
<th>Humic Matter (g/100 cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Piedmont</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dung + <em>O. gazella</em></td>
<td>7.54 ± 0.02a</td>
<td>0.00 ± 0.00a</td>
<td>10.26 ± 0.27a</td>
<td>100.00 ± 0.00a</td>
<td>0.18 ± 0.00a</td>
</tr>
<tr>
<td>Dung + <em>O. taurus</em></td>
<td>7.39 ± 0.05a</td>
<td>0.02 ± 0.01a</td>
<td>8.29 ± 0.29b</td>
<td>99.89 ± 0.11a</td>
<td>0.15 ± 0.01a</td>
</tr>
<tr>
<td>Dung only</td>
<td>7.39 ± 0.03a</td>
<td>0.02 ± 0.02a</td>
<td>8.27 ± 0.40b</td>
<td>99.78 ± 0.22a</td>
<td>0.15 ± 0.01a</td>
</tr>
<tr>
<td>Pre-treatment</td>
<td>7.35 ± 0.04a</td>
<td>0.06 ± 0.03a</td>
<td>7.39 ± 0.14b</td>
<td>99.33 ± 0.38a</td>
<td>0.07 ± 0.01b</td>
</tr>
<tr>
<td><strong>Coastal plain</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dung + <em>O. gazella</em></td>
<td>5.64 ± 0.03ab</td>
<td>1.08 ± 0.04a</td>
<td>4.32 ± 0.06a</td>
<td>75.11 ± 0.78a</td>
<td>1.62 ± 0.11a</td>
</tr>
<tr>
<td>Dung + <em>O. taurus</em></td>
<td>5.73 ± 0.04a</td>
<td>1.09 ± 0.02a</td>
<td>4.02 ± 0.09ab</td>
<td>73.00 ± 0.96a</td>
<td>1.58 ± 0.15a</td>
</tr>
<tr>
<td>Dung only</td>
<td>5.48 ± 0.02c</td>
<td>1.18 ± 0.01a</td>
<td>3.71 ± 0.09ab</td>
<td>68.11 ± 0.97b</td>
<td>1.64 ± 0.08a</td>
</tr>
<tr>
<td>Pre-treatment</td>
<td>5.55 ± 0.02bc</td>
<td>1.10 ± 0.04a</td>
<td>2.64 ± 0.05c</td>
<td>58.55 ± 0.78c</td>
<td>1.08 ± 0.04b</td>
</tr>
<tr>
<td><strong>Washed sand</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dung + <em>O. gazella</em></td>
<td>8.31 ± 0.08a</td>
<td>0.00 ± 0.00c</td>
<td>0.79 ± 0.09ab</td>
<td>100.00 ± 0.00a</td>
<td>0.07 ± 0.02a</td>
</tr>
<tr>
<td>Dung + <em>O. taurus</em></td>
<td>8.34 ± 0.07a</td>
<td>0.02 ± 0.01c</td>
<td>0.90 ± 0.02a</td>
<td>97.78 ± 1.11a</td>
<td>0.00 ± 0.00b</td>
</tr>
<tr>
<td>Dung only</td>
<td>7.70 ± 0.18b</td>
<td>0.09 ± 0.01b</td>
<td>0.54 ± 0.07bc</td>
<td>82.78 ± 2.42b</td>
<td>0.09 ± 0.00a</td>
</tr>
<tr>
<td>Pre-treatment</td>
<td>6.15 ± 0.02c</td>
<td>0.18 ± 0.02a</td>
<td>0.40 ± 0.00c</td>
<td>55.78 ± 5.78c</td>
<td>0.00 ± 0.00b</td>
</tr>
</tbody>
</table>

Different letters within columns and within soils indicate significant differences using Tukey’s Studentized Range Test (α = 0.05).
IV. Evaluating the effects of a methoprene feed additive on dung beetle (Coleoptera: Scarabaeidae and Geotrupidae) populations in North Carolina (USA)

Abstract

The use of mineral methoprene, in an area-wide (30.5 km²) effort to control the horn fly, Haematobia irritans L., was evaluated for non-target effects on dung beetle populations. Approximately 1,340 head of mixed breed cows and calves from ten adjoining farms, in Nash Co., NC, were treated with methoprene administered in a mineral formulation for 17 weeks during the summer of 2003. Horn fly densities on ten animals were determined weekly from each farm. Dung beetles were monitored every two weeks using dung-baited pitfall traps at two of the farms. Horn fly densities and dung beetle populations were compared to those from a pesticide-free farm in Wayne Co., NC. Methoprene reduced horn fly numbers below those in the control and below the economic threshold of 200 flies per animal on the treated animals during the entire treatment period. A total of 26,775 dung beetles, representing 17 species, was trapped from Wayne Co. while 26,546 total dung beetles, representing 16 species, were trapped from Nash Co.. The most common species at both sites included Onthophagus taurus Schreber, Aphodius lividus Olivier, Onthophagus pennsylvanicus Harold and Onthophagus hecate hecate Panzer. Preliminary data show that methoprene usage had no significant effect on these common Onthophagus species. The population of Aphodius lividus may have been reduced by methoprene, though it is not clear whether this species was naturally less common at the treated sites.

Keywords: methoprene, dung beetles, North Carolina, Haematobia irritans
THE HORN FLY, *Haematobia irritans* (L.), is a major pest of cattle in the southeastern United States (Hogsette et al. 1991, Watson et al. 2002). Both sexes of this dung-breeding species feed on blood. The generally accepted, standard economic threshold for this species is 200 flies per animal (Schreiber et al. 1987, Hogsette et al. 1991). In many parts of North Carolina flies reach numbers in excess of 1000 individuals per animal (Watson et al. 2002). Infestations of this species are detrimental to cattle production, causing severe irritation, annoyance, reduced feed efficiency and reduced weight gains (Campbell 1976, Kunz et al. 1991, Haufe 1982, Steelman et al. 1991).

The integrated management of horn flies includes sanitation through source reduction, biological control, mechanical control and the use of chemical pesticides (Kinzer et al 1991, Fincher 1990, Watson et al. 2002). Dung beetles play an important role in competing for dung resources with this species by rapidly consuming and shredding dung pats before fly larvae can reach adulthood (Blume et al. 1973, Legner and Warkentin 1991). In areas where dung beetles are extremely diverse and abundant, pats can be consumed within 5 days of deposition (Gillard 1967). However, in North Carolina dung beetle populations may not be sufficient to fully control the horn fly. Various insecticides, including pyrethroids and organophosphates, proved efficient at controlling this species in the past (Byford et al 1999). Unfortunately the horn fly is resistant to many of these chemicals (Barton et al. 1989, Cilek et al. 1991, Sheppard and Joyce 1992). Relying on pyrethroid or organophosphate insecticides as the single strategy for horn fly control will result in resistance within 3-4 years (Byford et al. 1999). Rotating to a different insecticide class, e.g. insect growth regulators, may delay the onset of organophosphate or pyrethroid resistance. Methoprene (isopropyl 11-methoxy-3,7,11-
trimethyl-2,4-dodecadienoate) is an insect growth regulator (IGR) that mimics juvenile hormone in insects. It has been used to control various pests of cattle, including the horn fly, face fly (*Musca autumnalis* DeGeer), house fly (*Musca domestica* L.) and stable fly [*Stomoxys calcitrans* (L.)] (Harris et al. 1973, Miller and Uebel 1974). Methoprene is typically administered to cattle in a mineral supplement. Excreted with the dung, methoprene effectively controls developing horn fly larvae.

Various commonly used insecticides and anthelmintics have been shown to cause mortality in non-target organisms, particularly dung beetles. Diflubenzuron, a chitin synthesis inhibitor, effectively controls horn flies but is also lethal to dung beetles developing in treated dung even up to 7 weeks after treatment (Fincher 1991). The residues of several macrocyclic lactones (abamectin, ivermectin, avermectin and eprinomectin) and other anthelmintics, including dichlorvos, coumaphos, ruelene, phenothiazine and piperazine, are also lethal to dung beetles (Blume et al. 1976, Fincher 1992, Doherty et al. 1994, Wardhaugh et al. 2001, Lumaret and Errouissi 2002). Moxidectin, a milbemycin macrocyclic lactone, is relatively non-toxic to dung beetles compared to other anthelmintics, but provides less control against horn flies (Doherty et al. 1994, Floate et al. 2001, Wardaugh et al 2001).

Studies to date have produced conflicting evidence of the effects of methoprene on dung beetles feeding on treated dung. In the laboratory, Blume et al. (1974) found that cattle fed methoprene (in a gelatin capsule) at a rate of 1mg/kg produced dung that reduced *Onthophagus gazella* (F.) survival by 1.8% the day after treatment and 32.6% by day five. Fincher (1991) treated an animal with 3.8 mg/kg of methoprene in bolus form
and subjected *O. gazella* to the treated dung. He found little difference in the percent eclosion of *O. gazella* when fed treated and untreated dung in the laboratory.

With conflicting data from laboratory studies and the lack of field studies it is difficult to conclude the detrimental effects of methoprene on dung beetle mortality, or its effects on dung beetle populations. This study was performed to evaluate the effects of area-wide methoprene use on populations of dung beetles in North Carolina.

**Materials and Methods**

Ten adjoining farms were identified in Nash Co., NC, to develop an area wide (30.5 km$^2$) study with 1,340 head of mixed breed cows and calves. Cattle were administered 0.12% proprietary methoprene mineral (Sam Galphin Services, 6509 Saddle Path Circle, Raleigh, NC 27600) from June 9 (week two of the experiment) through September of 2003. Cattle treated with methoprene mineral were held on pasture separate from the control groups, a pasture based dairy and a beef herd, located at the Center for Environmental Farming Systems (CEFS) in Wayne Co., NC. Cattle breeds at CEFS include Holstein and Jersey on the dairy, and Angus and Senepol/Angus cross on the beef unit.

Horn flies were counted on the back, sides and belly of 10 animals from each of the farms (10 farms from Nash Co. and one farm from Wayne Co.) to monitor changes in the horn fly densities. Fly populations were monitored for two weeks to establish pretreatment densities prior to treatment. Fly populations were counted weekly on Nash Co. (treated) and Wayne Co. (control) cattle at approximately the same time of day.
Twenty dung-baited pitfall traps were located near Nashville, NC (10 at the Bass Farm and 10 at the Rose Hill Farm) and twenty traps were located at the CEFS farm in Goldsboro, NC (equally divided between a dairy unit and a beef unit). Traps were placed at 50-meter intervals in areas where cattle actively grazed. Trapping occurred for a 24-hour period at 2-week intervals from June 4, 2003 to September 23, 2003. Beetles were identified to species in the laboratory.

The effect of methoprene on common species, including *Onthophagus taurus*, *Aphodius lividus*, *Onthophagus pennsylvanicus* and *Onthophagus hecate hecate*, was compared by analyzing mean trap catches for each county. Weekly means were analyzed using SAS 8.2 and separated using Tukey’s Studentized Range Test ($\alpha = 0.05$) (PROC GLM, SAS Institute 2001).

**Results and Discussion**

Formulated in a mineral salt, methoprene effectively controlled horn flies when used in the area wide fly management program (Figure 1). Pretreatment horn fly densities on the CEFS farm were nearly twice that of the treatment farms. Mean horn fly densities were below the established fly threshold of 200 flies per animal throughout the study for the treated animals.

During the 17-week study 26,775 dung beetles were trapped from the control farms (23,960 from the dairy unit and 2,815 from the beef unit) while 26,546 beetles were trapped from Nash Co. (20,583 from the Rose Hill farm and 5,963 from the Bass farm) (Table 1). Sixteen species of beetles were identified from Nash Co. traps, while 17 species were identified from Wayne Co. traps.
Dominant species of dung beetles are those that are abundant, comprising >5% of the total population (Howden and Scholtz 1986). The most abundant species at the Goldsboro dairy unit were *Onthophagus taurus* (72.17%) and *Aphodius lividus* (19.62%) (Table 1). At the beef unit, *O. taurus* also dominated the dung beetle fauna, comprising 55.52% of all beetles trapped. Additionally, *O. pennsylvanicus* (18.33%), *A. lividus* (14.42%) and *Onthophagus hecate hecate* (6.04%) were abundant at this unit.

*Onthophagus taurus* dominated the beetle fauna in Nash Co. as well, comprising 84.76 and 75.62% of the population at the Rose Hill and Bass farms, respectively. Another abundant species at Rose Hill was *O. pennsylvanicus* (10.91%) while dominant species at the Bass farm included *O. pennsylvanicus* (9.86%), *O. h. hecate* (6.41%) and *Aphodius erraticus* L. (5.15%).

It is not surprising that *Onthophagus taurus* dominated both farms in Nash Co., considering this species was dominant at both the CEFS site and a site in Salisbury, NC (Rowan Co.) in a previous seasonal study (Chapter II of this thesis). Interestingly though, the two common native species, *Onthophagus h. hecate* and *O. pennsylvanicus*, were more numerous in Nash Co. than in Wayne Co. (Table 1). Perhaps, *O. hecate* and *O. pennsylvanicus* assumed a more prominent role in the dung beetle community since *A. lividus* and *O. gazella* were less common in Nash Co. relative to the controls. If *A. lividus* and *O. gazella* become more abundant in Nash Co. we may see a change in dung beetle composition.

Peaks in beetle activity did not correspond to precipitation or temperatures (Figures 2 and 3). At Rose Hill (Nash Co.), over 5,000 beetles were trapped during weeks 7 and 17 (July 16 and September 23, respectively), while at the CEFS dairy unit
comparable numbers occurred only during week 13 (August 26) (Figures 2 and 3). Far fewer beetles were trapped from the Bass farm and the CEFS beef unit than Rose Hill or the CEFS dairy unit. Beetle totals exceeded 1,000 only during weeks one and 13 at the Bass farm, and never exceeded 1,000 at the CEFS beef unit (Figures 2 and 3).

Week by week changes in the number of trapped beetles suggests methoprene did not have a significant impact on the beetle population. Pooling each county’s trap catches, I compared mean trap catches for the control (Wayne Co) to that of the treatment (Nash Co.) for the most common species, *O. taurus*, *A. lividus*, *O. pennsylvanicus* and *O. h. hecate*. During week one, trap catches were statistically higher (*P* < 0.05) for the *Onthophagus* species, and numerically higher for *A. lividus* in Nash Co. (treated) than in Wayne Co. (control) (Figures 4-7). By week 3, though, trap catches declined in Nash Co. and increased in Wayne Co., leading to significantly less of the common species being trapped from Nash Co. (Figures 4-7). Since methoprene does not cause adult mortality and treatments were initiated during week two of the study, the decline in trapped dung beetles during week 3 could not be attributed to the methoprene treatment (EXTOXNET).

*Onthophagus taurus* numbers were significantly higher (*P* < 0.05) in Nash Co. 5 and 15 weeks post-treatment and were not statistically different from the control county 3, 7, 9 and 13 weeks post-treatment (Figure 4). Only during week 13 (11 weeks post-treatment) were trap catches significantly higher (*P* < 0.05) in Wayne Co. *Onthophagus taurus* completes its lifecycle, from egg to adult, in about 4-5 weeks (30.03-35.0 days) at 26°C in the laboratory (Wardaugh et al. 2001). Field temperatures averaged 24°C (average temperature range = 20.1-28.9°C) in Nash Co. during the study, possibly
increasing the development time (Figure 2). Therefore, given a conservative range of 4-7 weeks for development, I expected a reduction in the numbers of *O. taurus* collected from the traps during weeks 6 through 9 (Wardaugh et al. 2001). However, trap catches in Nash Co. were significantly greater than Wayne Co. catches during week 7 and not statistically different during week 9 (Figure 4). Traps averaged significantly less *O. taurus* in Nash Co. during week 13, but not during weeks 15 and 17.

Nash Co. trap catches for *Aphodius lividus* were only higher than Wayne Co. during the first week, though differences were not significant (Figure 5). During weeks 3, 7, 13, 15, and 17 Wayne Co. traps yielded, significantly more *A. lividus*, with trap catches being numerically higher during the remainder of the weeks (Figure 5). Thus, *Aphodius lividus* appeared the most affected by methoprene of the common species. However, at no time was *A. lividus* statistically more abundant in Nash Co. than in Wayne Co. Nash Co. may have a lower background population of this species, and may be influenced by other factors independent of the methoprene treatment.

Trap catches for *Onthophagus pennsylvanicus* were numerically higher in Nash Co. during all of the weeks, except during week 3 and week 13 (where both counties had similar, not statistically different, catches) (Figure 6). Nash Co. traps yielded significantly more *O. pennsylvanicus* on weeks 7, 11 and 17. The lifecycle of *Onthophagus pennsylvanicus*, from egg to adult, is approximately 3 weeks (Howden and Cartwright 1963). Three weeks after initial treatment with methoprene (week 5) there was no significant difference (*P* < 0.05) between the Wayne Co. population and the Nash Co. population (with the latter being greatest) (Figure 5). During the following trapping date (week 7), significantly more (*P* < 0.05) *O. pennsylvanicus* were trapped in Nash than
Wayne, with traps averaging 80.65 and 16.15 beetles, respectively. Given a 3 week development period, all progeny feeding on treated dung would have developed and emerged by week 7. As a result there seems to be no evidence for a reduction in the population due to methoprene.

In addition to week 3, mean trap catches of *Onthophagus hecate hecate* were significantly lower in Nash Co. than Wayne Co. during week 5 (Figure 7). However, during weeks 7, 9, 13 and 15 Nash trap catches of this species were significantly higher than Wayne Co. catches, and during weeks 11 and 17 there was no significant difference in mean trap catch between the two counties. To the best of my knowledge the development and life table parameters for *O. h. hecate* have not been studied. Assuming *O. h. hecate* has a similar developmental time as *O. taurus*, we would expect 4 to 7 weeks to pass after treatment before observing a reduction in the *O. h. hecate* population. However, at 5 and 7 weeks post-treatment (weeks 7 and 9), the Nash Co. population was significantly higher (*P* < 0.05) than the Wayne Co. population (Figure 7).

In laboratory studies, methoprene had no detrimental effect on *Onthophagus gazella* (Fincher 1991). Data presented in this experiment suggests that 3 species of common dung beetles, *O. taurus*, *O. pennsylvaniaicus*, and *O. hecate* were not adversely affected by the use of methoprene. A fourth species, *Aphodius lividus*, seemed to have consistently lower numbers in the treated area than the control area. Though the administration of methoprene may have reduced the population of this species, it is not apparent whether other factors contributed to this species’ low population in the treatment area. Similarly, the local dung beetle species *Onthophagus gazella* (F.) was abundant in Wayne Co. (1,025 individuals trapped during the 17 weeks), but was rare in the treatment area.
area (8 individuals trapped). Although these data show no clear, short-term effects of methoprene on dung beetle populations in the field, there is a need for further studies to determine the lasting impact of methoprene on over-wintering beetle populations, particularly if methoprene remains an effective means to control of the horn fly in this region.
Acknowledgments

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Table 1. Species and number of dung beetles trapped from Goldsboro (Center for Environmental Farming Systems) and Nashville (Rose Hill and Bass farms), NC from June 2003 through September 2003.

<table>
<thead>
<tr>
<th>Species</th>
<th>Goldsboro Dairy Unit</th>
<th>Goldsboro Beef Unit</th>
<th>Nashville Rose Hill</th>
<th>Nashville Bass</th>
<th># of Beetles (% of Total)</th>
<th># of Beetles (% of Total)</th>
<th># of Beetles (% of Total)</th>
<th># of Beetles (% of Total)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aphodius campestris</td>
<td>4 (0.02)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>4,700 (19.62)</td>
<td>406 (14.42)</td>
<td>275 (1.34)</td>
<td>134 (2.25)</td>
</tr>
<tr>
<td>A. erraticus&lt;sup&gt;a&lt;/sup&gt;</td>
<td>52 (0.22)</td>
<td>72 (2.56)</td>
<td>193 (0.94)</td>
<td>307 (5.15)</td>
<td>307 (5.15)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A. fimetarius&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-</td>
<td>-</td>
<td>7 (0.03)</td>
<td>9 (0.15)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A. granarius&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-</td>
<td>-</td>
<td>1 (&lt;0.01)</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A. haemorrhoidalis&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-</td>
<td>-</td>
<td>9 (0.04)</td>
<td>2 (0.03)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A. lividus&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4,700 (19.62)</td>
<td>406 (14.42)</td>
<td>275 (1.34)</td>
<td>134 (2.25)</td>
<td>4,700 (19.62)</td>
<td>406 (14.42)</td>
<td>275 (1.34)</td>
<td>134 (2.25)</td>
</tr>
<tr>
<td>A. rubeolus</td>
<td>9 (0.04)</td>
<td>1 (0.04)</td>
<td>-</td>
<td>-</td>
<td>9 (0.04)</td>
<td>1 (0.04)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>A. rusicola</td>
<td>3 (0.01)</td>
<td>1 (0.04)</td>
<td>-</td>
<td>-</td>
<td>3 (0.01)</td>
<td>1 (0.04)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Ataenius erratus</td>
<td>2 (0.01)</td>
<td>26 (0.92)</td>
<td>2 (0.01)</td>
<td>2 (0.01)</td>
<td>2 (0.01)</td>
<td>26 (0.92)</td>
<td>2 (0.01)</td>
<td>2 (0.01)</td>
</tr>
<tr>
<td>A. platensis</td>
<td>5 (0.02)</td>
<td>5 (0.18)</td>
<td>1 (&lt;0.01)</td>
<td>3 (0.05)</td>
<td>5 (0.02)</td>
<td>5 (0.18)</td>
<td>1 (&lt;0.01)</td>
<td>3 (0.05)</td>
</tr>
<tr>
<td>Ateuchus histeroides</td>
<td>-</td>
<td>-</td>
<td>1 (&lt;0.01)</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Canthon pilularius</td>
<td>1 (&lt;0.01)</td>
<td>1 (0.04)</td>
<td>-</td>
<td>-</td>
<td>1 (&lt;0.01)</td>
<td>1 (0.04)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>C. vigilans</td>
<td>1 (&lt;0.01)</td>
<td>-</td>
<td>1 (&lt;0.01)</td>
<td>2 (0.03)</td>
<td>1 (&lt;0.01)</td>
<td>-</td>
<td>1 (&lt;0.01)</td>
<td>2 (0.03)</td>
</tr>
<tr>
<td>Dichotomius carolinus</td>
<td>4 (0.02)</td>
<td>-</td>
<td>15 (0.07)</td>
<td>2 (0.03)</td>
<td>4 (0.02)</td>
<td>-</td>
<td>15 (0.07)</td>
<td>2 (0.03)</td>
</tr>
<tr>
<td>Geotrupes splendidus</td>
<td>-</td>
<td>-</td>
<td>1 (&lt;0.01)</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Onthophagus gazella&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>1,002 (4.18)</td>
<td>23 (0.82)</td>
<td>2 (0.01)</td>
<td>6 (0.10)</td>
<td>1,002 (4.18)</td>
<td>23 (0.82)</td>
<td>2 (0.01)</td>
<td>6 (0.10)</td>
</tr>
<tr>
<td>O. h. hecata</td>
<td>103 (0.43)</td>
<td>170 (6.04)</td>
<td>305 (1.48)</td>
<td>382 (6.41)</td>
<td>103 (0.43)</td>
<td>170 (6.04)</td>
<td>305 (1.48)</td>
<td>382 (6.41)</td>
</tr>
<tr>
<td>O. oklahomensis</td>
<td>4 (0.02)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>4 (0.02)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>O. pennsylvanicus</td>
<td>743 (3.10)</td>
<td>516 (18.33)</td>
<td>2,246 (10.91)</td>
<td>588 (9.86)</td>
<td>743 (3.10)</td>
<td>516 (18.33)</td>
<td>2,246 (10.91)</td>
<td>588 (9.86)</td>
</tr>
<tr>
<td>O. taurus&lt;sup&gt;a&lt;/sup&gt;</td>
<td>17,292 (72.17)</td>
<td>1,563 (55.52)</td>
<td>17,447 (84.76)</td>
<td>4,509 (75.62)</td>
<td>17,292 (72.17)</td>
<td>1,563 (55.52)</td>
<td>17,447 (84.76)</td>
<td>4,509 (75.62)</td>
</tr>
<tr>
<td>O. tuberculifrons</td>
<td>1 (&lt;0.01)</td>
<td>2 (0.07)</td>
<td>-</td>
<td>-</td>
<td>1 (&lt;0.01)</td>
<td>2 (0.07)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Phanaeus vindex</td>
<td>34 (0.14)</td>
<td>29 (1.03)</td>
<td>78 (0.38)</td>
<td>17 (0.29)</td>
<td>34 (0.14)</td>
<td>29 (1.03)</td>
<td>78 (0.38)</td>
<td>17 (0.29)</td>
</tr>
<tr>
<td>TOTAL</td>
<td>23,960</td>
<td>2,815</td>
<td>20,583</td>
<td>5,963</td>
<td>23,960</td>
<td>2,815</td>
<td>20,583</td>
<td>5,963</td>
</tr>
</tbody>
</table>

NOTE: (n=10) traps for all units

<sup>a</sup> Accidentally introduced species (Fincher and Woodruff, 1975; Gordon, 1983)

<sup>b</sup> Intentionally introduced species (Blume and Aga, 1978)
Figure 1. Mean horn fly densities on 10 methoprene treated cattle herds (Nash Co.) and one untreated control (Wayne Co.). Arrow indicates time of initial methoprene administration.
Figure 2. Top: weather data showing accumulated rainfall between trapping dates and average temperature (with maximum and minimum bars). Bottom: total beetles trapped during each trapping date. [Nash Co., NC]
Figure 3. Top: weather data showing accumulated rainfall between trapping dates and average temperature (with maximum and minimum bars). Bottom: total beetles trapped during each trapping date. [Wayne Co., NC]
Figure 4. Mean number of *Onthophagus taurus* per trap, throughout the 17 week study, in Nash Co. (Nashville) and Wayne Co. (Goldsboro), NC. Arrow indicates time of initial methoprene administration.

Means followed by different letters during each trapping date are significantly different (Tukey’s studentized range test, \( P < 0.05 \))
Figure 5. Mean number of *Aphodius lividus* per trap, throughout the 17 week study, in Nash Co. (Nashville) and Wayne Co. (Goldsboro), NC. Arrow indicates time of initial methoprene administration.

Means followed by different letters during each trapping date are significantly different (Tukey’s studentized range test, $P < 0.05$)
Figure 6. Mean number of *Onthophagus pennsylvanicus* per trap, throughout the 17 week study, in Nash Co. (Nashville) and Wayne Co. (Goldsboro), NC. Arrow indicates time of initial methoprene administration.

Means followed by different letters during each trapping date are significantly different (Tukey’s studentized range test, $P < 0.05$)
Figure 7. Mean number of *Onthophagus hecate hecate* per trap, throughout the 17 week study, in Nash Co. (Nashville) and Wayne Co. (Goldsboro), NC. Arrow indicates time of initial methoprene administration.

Means followed by different letters during each trapping date are significantly different (Tukey’s studentized range test, *P* < 0.05)
Appendix A:  
Descriptions, Seasonal Activity and Photos of Dung Beetles of North Carolina

SCARABAEIDAE: Aphodiinae

*Aphodius bicolor* Say 1823

(Native)

*Aphodius bicolor* is a medium sized (4.5-6.5mm) endocoprid beetle, characterized by a dark dorsum and a red-orange ventral surface and legs. Other characters include an emarginate clypeus with prominent angles (almost bidentate) and alutaceous elytral apices (Woodruff 1973, Harpootlian 2001) (Figure 1.A & B). *Aphodius bicolor* is a native species, with a strong preference for deer dung (Gordon 1983).

Seasonal activity of this species coincided with the onset of autumn and continued through the cooler months of the winter (Figure 5). *Aphodius bicolor* activity ceased prior to the end of winter (December, 2002) and did not resume before the trapping period terminated in September 2003.

*Aphodius campestris* Blatchley 1912

(Native)

*Aphodius campestris* is a small (2.5-4.0mm), yellow brown to reddish-brown aphodiine beetle. Additional characters include a mostly impunctate pronotum and pubescence on the elytral apices (Woodruff 1973, Harpootlian 2001) (Figure 1.C). *Aphodius campestris* as a surface feeding, native generalist rarely inhabiting deer dung (Gordon 1983).
Aphodius campestris is a warm season dung beetle, active from spring to autumn (Figure 6).

Aphodius distinctus (Müller 1776)

(Exotic: Europe)

Aphodius distinctus is a small (4.5-5.5mm) endocoprid beetle with a black head and pronotum, and characteristic dark markings on light brown elytra. This species has a characteristic mixture of small and large punctures on the pronotum (Harpootlian 2001) (Figure 1.D). Aphodius distinctus is an exotic generalist with a strong preference for open pastures and bovine dung (Gordon 1983).

Aphodius distinctus was abundant during the cooler months of autumn and winter, with fewer individuals being trapped during the spring. No specimens were collected during the summer months (see Figure 12 of chapter II).

Aphodius erraticus (Linnaeus 1758)

(Exotic: Europe)

Aphodius erraticus is a large (6.8-8.2mm) endocoprid dung beetle, characterized by a dull black head and pronotum, and tan to dark brown elytra. This species also has a characteristically large scutellum (1/5 to 1/3 the length of the elytra) and a black margined elytral suture (Harpootlian 2001) (Figure 1.E). Described as an imported generalist, A. erraticus prefers bovine dung in open pastures (Gordon 1983).

Aphodius erraticus adult beetles were active from early March until early July (see Figure 8 of chapter II).
**Aphodius fimetarius** (Linnaeus 1758)

(Exotic: Europe)

*Aphodius fimetarius* is a medium to large (6.5-8.5mm) endocoprid dung beetle. It is characterized by a shiny dorsum, including a black head and pronotum (with red anterior angles), and red to orange elytra. The head generally has three small tubercles (Woodruff 1973, Harpootlian 2001) (Figure 1.F & G). Like other imported *Aphodius*, *A. fimetarius* is a generalist preferring open pastures and bovine dung (Gordon 1983).

*Aphodius fimetarius* activity could be seen during the spring and early summer and also during late autumn (Figure 7).

**Aphodius granarius** (Linnaeus 1767)

(Exotic: Europe)

*Aphodius granarius* is a small to medium sized (3-5mm) endocoprid dung beetle, with an overall black to dark brown coloration. Other characters include irregular pronotal punctures and a scutellum that is depressed below the elytral surfaces (Woodruff 1973, Harpootlian 2001) (Figure 1.H). This introduced endocoprid generalist prefers bovine dung in open settings (Gordon 1983).

*Aphodius granarius* were only captured from the late winter until the early summer (see Figure 11 of chapter II).
Aphodius haemorrhoidalis (Linnaeus 1758)

(Exotic: Europe)

*Aphodius haemorrhoidalis* is a medium sized (4-5mm) endocoprid dung beetle. This species has a black body with red elytral apices (and in many specimens, red elytral humeri). Other characters of this species include a distinctly large and punctured scutellum (1/5 to 1/3 the length of the elytra) and a trituberculate head (Woodruff 1973, Harpootlian 2001) (Figure 1.I). Characterized as a generalist endocoprid beetle, *A. haemorrhoidalis* prefers open pastures and bovine dung (Gordon 1983).

*Aphodius haemorrhoidalis* was captured during the spring and summer months of the year (April through early September) (Figure 8).

Aphodius lividus (Olivier 1789)

(Exotic: Europe)

*Aphodius lividus* is a small to medium sized (3-6mm), two-toned brown and yellow endocoprid dung beetle. Characters include a shiny surface, lightly colored with large dark areas covering much of the elytra and pronotum. Three tubercles are often present on the head of this species (Woodruff 1973, Harpootlian 2001) (Figure 1.J). *Aphodius lividus* is a surface feeding generalist that prefers bovine dung in open pastures (Gordon 1983).

*Aphodius lividus* had a long period of activity in North Carolina. Adult beetles were taken from early March through late November and early December (see Figure 7 of chapter II).
Aphodius lutulentus Haldeman 1843

(Native)

*Aphodius lutulentus* is a medium sized (5.5-7mm) endocoprid dung beetle. This beetle can be recognized by its dull black or gray surface color. Other characters include an emarginate clypeus with strong, tooth-like angles and elytra with indistinct striae among flat intervals (Woodruff 1973, Harpootlian 2001) (Figure 1.K & L). *Aphodius lutulentus* is a native species with a strong preference for deer dung (Gordon 1983). It is also considered it to be an autumnal species, present from October through February (Gordon 1983).

*A. lutulentus* was only present during the year from late autumn until early spring (November through early April). Peak activity occurred during late December (Figure 9).

*Aphodius prodromus* (Brahm 1790)

(Exotic: Europe)

New State Record

*Aphodius prodromus* is a small to medium sized (3.5-5.5mm) endocoprid dung beetle. Characteristics of this species include a shiny black head and pronotum (with tan lateral edges), and tan, alutaceous elytra with pubescence throughout (Figure 1.M). As with other exotic species, *Aphodius prodromus* is a generalist, preferring open pastures and bovine dung (Gordon 1983).

All *A. prodromus* were taken from late winter through early spring (late February through early April) (Figure 10).
**Aphodius rubeolus** Beauvois 1805

(Native)

*Aphodius rubeolus* is a small to medium sized (3.5-5mm) endocoprid dung beetle. This species is characteristically red-brown in color. Other characters include blunt, spatulate hind tibial spurs, and elytra with pubescent apices (Woodruff 1973, Harpootlian 2001) (Figure 1.N). *Aphodius rubeolus* is a native generalist and surface feeder, which does not readily utilize deer dung (Gordon 1983).

This species was trapped during the summer and early fall (June through September) (Figure 11).

**Aphodius rusicola** Melsheimer 1845

(Native)

*Aphodius rusicola* is a small to medium sized (3.5-5.5mm) endocoprid dung beetle. This species has a trituberculate head with an emarginate clypeus (angles obtusely rounded). *Aphodius rusicola* also has a brown to black body color (Woodruff 1973, Harpootlian 2001) (Figure 1.O). This native species is associated with deer dung, also utilizes other types of dung, including that of cattle (Gordon 1983).

All *A. rusicola* were taken during May and June (Figure 12).

**Aphodius stupidus** Horn 1870

(Native)

*Aphodius stupidus* is a small to medium sized (3-5mm) endocoprid dung beetle. Characters include a dull, black or gray surface and dull elytra with long, stout
pubescence running the length of the intervals (Woodruff 1973, Harpootlian 2001) 
(Figure 2.A). *Aphodius stupidus* is characterized as a native beetle preferring deer dung 
(Gordon 1983).

Gordon (1983) reported this species as having a seasonal distribution from October to December. The two *Aphodius stupidus* specimens collected during this study occurred during March and January (Figure 13).

*Aphaenius erratus* Fall 1930

(Native)

*Aphaenius erratus* is a medium sized (4.4-5.9mm) endocoprid dung beetle. This species is characteristically shiny black or dark brown and is moderately elongate (elytra much longer than pronotum) (Woodruff 1973, Harpootlian 2001) (Figure 2.B).

*Aphaenius erratus* individuals were trapped as early as March. However, most were trapped between June and early November (Figure 14).

*Aphaenius imbricatus* (Melsheimer 1844)

(Native)

*Aphaenius imbricatus* is a small (3.3-4.3mm) endocoprid dung beetle. It is easily recognized by having a dull gray, argillaceous body and blunt yellow setae arising from the pronotal punctures and elytral intervals (Woodruff 1973, Harpootlian 2001) (Figure 2.C).

*Aphaenius imbricatus* was trapped during March and April (Figure 15).
*Ataenius miamii* Cartwright 1934  
(Native)

*Ataenius miamii* is a small (3.2-4.2mm) endocoprid dung beetle. Characteristics of this species include a dull, brown, body surface, with cariniform elytral intervals having short setae (Woodruff 1973, Harpootlian 2001) (Figure 2.D).

The only *Ataenius miamii* was taken in March from Goldsboro (Figure 16).

*Ataenius platensis* (Blanchard 1846)  
(Native)

*Ataenius platensis* is a small (3.5-4.9mm) endocoprid dung beetle. This species has a shiny, black to red body coloration and fine rugulae on the clypeus. The elytra bear noticeable striae (Woodruff 1973, Harpootlian 2001) (Figure 2.E).

*Ataenius platensis* was trapped from April through October (Figure 17).

*Ataenius simulator* Harold 1868  
(Native)

*Ataenius simulator* is a medium sized (3.7-4.9 mm) endocoprid dung beetle. This species has a brown to black body coloration. *A. simulator* has a characteristically convex, rugose clypeus with reflexed angles (Woodruff 1973, Harpootlian 2001) (Figure 2.F).

All *A. simulator* were taken during March and April of period one (Figure 18).
SCARABAEIDAE: Scarabaeinae

*Canthon pilularius* (Linnaeus 1758)

(Native)

*Canthon pilularius* is a large (12-17 mm) telecoprid dung beetle with a body coloration ranging from black to slightly green or bronze. *Canthon pilularius* has a bidentate clypeus, small eyes and a combination of coarse and fine granules covering the entire dorsal surface (Woodruff 1973, Harpootlian 2001) (Figure 2.G & H).

*Canthon pilularius* was collected May through September (Figure 19).

*Canthon vigilans* LeConte 1858

(Native)

*Canthon vigilans* is a large (13-20 mm) telecoprid dung beetle with a black to purple body coloration. This species has characteristically large eyes for the genus, a bidentate clypeus and a body covered by a mixture of coarse and fine granules (Woodruff 1973, Harpootlian 2001) (Figure 2.I & J).

*Canthon vigilans* was taken during September and August (Figure 20).

SCARABAEIDAE: Coprinae

*Copris minutus* (Drury 1770)

(Native)

*Copris minutus* is a medium to large (8-13 mm) paracoprid dung beetle with a shiny, black body coloration. The head of this species bears a long horn in both sexes and
has a deeply notched clypeus. This species has 8 elytral striae (Woodruff 1973, Harpootlian 2001) (Figure 2.K & L).

*Copris minutus* individuals were taken during July and September through November (Figure 21).

**Dichotomius carolinus** (Linnaeus 1767)

*(Native)*

*Dichotomius carolinus* is the largest dung beetle in the U.S. (20-30mm). This species has a shiny black dorsal color, with reddish-brown setae along the lateral, pronotal edges. Other characters include a blunt process or horn on the head, a pronotum with a convex posterior portion leading to an abruptly convex anterior portion, and seven elytral striae, often packed with soil near apices (Woodruff 1973, Harpootlian 2001) (Figure 2.M & N).

All *D. carolinus* were taken during one trapping date in September (Figure 22).

**Onthophagus gazella** (Fabricius 1787)

*(Exotic: Afro-Asian)*

**New State Record**

*Onthophagus gazella* is large for the genus (10-13mm). It is easily distinguished from other U.S. members of the genus by its two-tone brown/bronze, dull surface. Major males have a short, upright horn above each eye and long, thin fore tibiae. Females lack horns but have thicker fore tibiae and two median protuberances on the anterior of the pronotum (Harpootlian, 2001) (Figure 3.A-F).
*Onthophagus gazella* activity was seen from May through early November with peak activity during August, September and October (see Figure 9 of chapter II).

*Onthophagus hecate hecate* (Panzer 1794)  
(Native)  

*Onthophagus hecate hecate* is a medium sized beetle (5.2-9.5mm). It is characterized by a dull gray to black surface coloration, generally with long pubescence. This species is easily recognized by the elongate tubercles present on the pronotum. Major males have a pointed, reflexed clypeus and a spatulate (and many times forked) process extending from the anterior area of the pronotum, over the head. Females Lack these characters, but may have a small, transverse ridge on the anterior portion of the pronotum. This subspecies is replaced by another subspecies, *O. h. blatchleyi* Brown, in Florida. (Woodruff 1973, Harpootlian 2001) (Figure 3.G-J).

*Onthophagus hecate hecate* was present during much of the year at both sites, emerging in March and active through the summer. Individuals were trapped through November and, rarely, in December and January (see Figure 13 of chapter II).

*Onthophagus oklahomensis* Brown 1927  
(Native)  

*Onthophagus oklahomensis* is a small member of this genus (2-4.1mm). This species can be recognized by its small size, lack of secondary sex characters and shiny black coloration. It differs from *O. pennsylvanicus* in having two different sized pronotal
punctures, and by being smaller and shinier (Woodruff 1973, Harpootlian 2001) (Figure 3.K).

Specimens of *O. oklahomensis* were taken during May, June, July and September (Figure 23).

**Onthophagus pennsylvanicus** Harold 1871  
(Native)

*Onthophagus pennsylvanicus* is a small member of this genus (3.3-5mm). This species can be recognized by its small size, lack of secondary sex characters and dull black coloration. It differs from *O. oklahomensis* in having pronotal punctures of one size (Woodruff 1973, Harpootlian 2001) (Figure 3.L).

This species was active during most of the year, particularly from late March through early November. Few individuals were trapped during other parts of the year (see Figure 10 of chapter II).

**Onthophagus taurus** (Schreber 1759)  
(Exotic: Europe, Asia)

*Onthophagus taurus* is a medium to large member of this genus (8-10mm). This species is black to brown, often with lighter, reddish elytra. The dorsal surface of this species is subtly shining, without pubescence. Pronotal punctures are shallow and sparse. Major males are readily identified by a large curved horn above each eye (the pair resembling bull horns) with impressions in the pronotum to receive them. Females lack
such horns and have a generally convex pronotum (Harpootlian, 2001) (Figure 3.M-O; Figure 4.A & B).

*Onthophagus taurus* was active during the warmer months of the year, including late March through late October/early November. Peaks in activity occurred in June in Goldsboro (>11,000 beetles trapped), and late August in Salisbury (>1,600 beetles trapped) (see Figure 6 of chapter II).

*Onthophagus tuberculifrons* Harold 1871

(Native)

*Onthophagus tuberculifrons* is a small member of this genus (3-5.5mm). This species is readily distinguished from *O. pennsylvanicus* and *O. oklahomensis* by the following characters: orange maculation on elytra (especially the apices), acutely emarginate clypeus and two protuberances on the frons (Woodruff 1973, Harpootlian 2001) (Figure 4.C).

*Onthophagus tuberculifrons* was active throughout the year. The greatest single trap catch occurred in January (Figure 24).

*Phanaeus vindex* MacLeay 1819

(Native)

*Phanaeus vindex* is a large (13-20mm) paracoprid dung beetle. Its size and metallic sheen (red-orange-yellow pronotum; green elytra) easily distinguish this species from others. Major males have a large, curved horn on their head and posterior pronotal
angles produced. Females may have a small head tubercle, but have a normal pronotum
(Woodruff 1973, Harpootlian 2001) (Figure 4.D-H).

*Phanaeus vindex* was trapped from late March/early April through late
November. Peaks in activity (from Goldsboro populations) occurred during the late
spring (April through early June) and the late summer (August through October) (Figure
25).

**GEOTRUPIDAE: Geotrupinae**

*Geotrupes blackburnii blackburnii* (Fabricius 1781)

(Native)

*Geotrupes blackburnii blackburnii* is a large (10-18mm) dung beetle. This species
can be distinguished by its relatively large size, convex profile, dark, black/blue dorsal
surface and metallic blue underside. It also has lateral and median punctures on the
pronotum and distinct elytral striae (Woodruff 1973, Harpootlian 2001) (Figure 2.O).

*Geotrupes blackburnii blackburnii* was active from late September through late
April in Goldsboro. The single individual trapped from Salisbury was taken during
October (Figure 26).
References Cited


Figure 1. Aphodius species: A. bicolor (dorsal); B. bicolor (lateral); C. campestris; D. distinctus; E. erraticus; F. fimetarius (dorsal); G. fimetarius (lateral); H. granarius; I. haemorrhoidalis; J. lividus; K. lutulentus (dorsal); L. lutulentus (lateral); M. prodromus; N. rubeolus; O. rusicola
Figure 2. A. Aphodius stupidus; B. Ataenius erratus; C. At. imbricatus; D. At. miamii; E. At. platensis; F. At. simulator; G. Canthon pilularius; H. C. pilularius (head and pronotum); I. Canthon vigilans; J. C. vigilans (head and pronotum); K. Copris minutus (dorsal); L. C. minutus (lateral); M. Dichotomius carolinus (dorsal); N. D. carolinus (lateral); O. Geotrupes blackburnii blackburnii
Figure 3. *Onthophagus* species: A. *gazella* (♀ dorsal); B. *gazella* (♀ lateral); C. *gazella* (♀ head); D. *gazella* (♂ dorsal); E. *gazella* (♂ lateral); F. *gazella* (♂ head); G. *hecate hecate* (♀ dorsal); H. *h. hecate* (♀ lateral); I. *h. hecate* (♂ dorsal); J. *h. hecate* (♂ lateral); K. *oklahomensis*; L. *pennsylvanicus* (lateral); M. *taurus* (♀ dorsal); N. *taurus* (♀ lateral); O. *taurus* (♂ dorsal)
Figure 4. A. *O. taurus* (♂ lateral); B. *O. taurus* (♀ head); C. *O. tuberculifrons*; D. *Phanaeus vindex* (♀ dorsal); E. *P. vindex* (♀ lateral); F. *P. vindex* (minor ♂ dorsal); G. *P. vindex* (♂ dorsal); H. *P. vindex* (♂ lateral)
Figure 5. Seasonal activity of *Aphodius bicolor* in Goldsboro*.
[solid line = Dairy; dashed line = Beef]
* No *A. bicolor* were taken from Salisbury
Figure 6. Seasonal activity of *Aphodius campestris* in Goldsboro*. [solid line = dairy unit; dashed line = beef unit]

* No *A. campestris* were taken from Salisbury
Figure 7. Seasonal activity of *Aphodius fimetarius* in Salisbury (top) and Goldsboro (bottom). [solid line = dairy unit; dashed line = beef unit]
Figure 8. Seasonal activity of *Aphodius haemorrhoidalis* in Salisbury*.

* No *A. haemorrhoidalis* were taken from Goldsboro
Figure 9. Seasonal activity of *Aphodius lutulentus* in Goldsboro*.
[solid line = dairy unit; dashed line = beef unit]
* No *A. lutulentus* were taken from Salisbury
Figure 10. Seasonal activity of *Aphodius prodromus* in Salisbury*.

* No *A. prodromus* were taken from Goldsboro
Figure 11. Seasonal activity of *Aphodius rubeolus* in Goldsboro*. [solid line = dairy unit; dashed line = beef unit]

* No *A. rubeolus* were taken from Salisbury
Figure 12. Seasonal activity of *Aphodius rusicola* in Goldsboro*. [solid line = dairy unit; dashed line = beef unit]

* No *A. rusicola* were taken from Salisbury
Figure 13. Seasonal activity of *Aphodius stupidus* in Goldsboro*. [solid line = dairy unit; dashed line = beef unit]

* No *A. stupidus* were taken from Salisbury
Figure 14. Seasonal activity of *Ataenius erratus* in Goldsboro*. [solid line = dairy unit; dashed line = beef unit]

* No *A. erratus* were taken from Salisbury
Figure 15. Seasonal activity of *Ataenius imbricatus* in Goldsboro*.
[solid line = dairy unit; dashed line = beef unit]
* No *A. imbricatus* were taken from Salisbury
Figure 16. Seasonal activity of *Ataenius miamii* in Goldsboro*.
[solid line = dairy unit; dashed line = beef unit]
* No *A. miamii* were taken from Salisbury
Figure 17. Seasonal activity of *Ataenius platensis* in Salisbury (top) and Goldsboro (bottom). [solid line = dairy unit; dashed line = beef unit]
Figure 18. Seasonal activity of *Ataenius simulator* in Goldsboro*. [solid line = dairy unit; dashed line = beef unit]

* No *A. simulator* were taken from Salisbury
Figure 19. Seasonal activity of *Canthon pilularius* in Goldsboro*. [solid line = dairy unit; dashed line = beef unit]

* No *C. pilularius* were taken from Salisbury
Figure 20. Seasonal activity of *Canthon vigilans* in Goldsboro*.
[solid line = dairy unit; dashed line = beef unit]
* No *C. vigilans* were taken from Salisbury
Figure 21. Seasonal activity of *Copris minutus* in Salisbury (top) and Goldsboro (bottom). [solid line = dairy unit; dashed line = beef unit]
Figure 22. Seasonal activity of *Dichotomius carolinus* in Goldsboro*.  
[solid line = dairy unit; dashed line = beef unit]  
* No *D. carolinus* were taken from Salisbury
Figure 23. Seasonal activity of *Onthophagus oklahomensis* in Goldsboro*. [solid line = dairy unit; dashed line = beef unit]

* No *O. oklahomensis* were taken from Salisbury
Figure 24. Seasonal activity of *Onthophagus tuberculifrons* in Goldsboro*.
[solid line = dairy unit; dashed line = beef unit]
* No *O. tuberculifrons* were taken from Salisbury
Figure 25. Seasonal activity of *Phanaeus vindex* in Salisbury (top) and Goldsboro (bottom). [solid line = dairy unit; dashed line = beef unit]
Figure 26. Seasonal activity of *Geotrupes blackburnii blackburnii* in Salisbury (top) and Goldsboro (bottom). [solid line = dairy unit; dashed line = beef unit]