Benefits of Dung Beetles (Coleoptera: Scarabaeidae) on Nutrient Cycling and Forage Growth in Alpaca Pastures

Mary Elin Arnaudin

Thesis submitted to the faculty of Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of

Master of Science
in
Crop and Soil Environmental Sciences

Christopher D. Teutsch (Chair)

Azenegashe O. Abaye

Stephan A. J. Wildeus

David Wesley Watson

28 February 2012

Blacksburg, Virginia

Keywords: dung beetles, crabgrass, alpaca, nutrient cycle

Benefits of Dung Beetles (Coleoptera: Scarabaeidae) on Nutrient Cycling and Forage Growth in Alpaca Pastures

Mary Elin Arnaudin

ABSTRACT

Alpacas have been gaining prominence in the U.S. since the early 1980s. In pastures, dung beetle activity has been shown to enhance the degradation and incorporation of dung into the soil. The benefits of this activity have been quantified for cattle, but not for alpacas. The objectives of this study were to document the dung beetle species present in alpaca pastures, and to evaluate the impact of dung beetle activity on the growth of a common summer annual grass. In 2010 and 2011, dung beetle species present in alpaca pastures located at Virginia State University (VSU), were evaluated weekly from late May until late August. Eleven species of dung beetles were found, with *Onthophagus taurus* Schreber being the most dominant. In 2011, a greenhouse study was conducted at Virginia Tech's Southern Piedmont Research Station. Treatments included a control (no dung, no beetles), dung only, dung with five pairs of *O. taurus*, and dung that was allowed to be colonized in alpaca pastures at VSU. The addition of *O. taurus* and the field colonization both significantly increased total yield over the no dung control by 10% and 14%, respectively. These results indicate that healthy and diverse dung beetle communities occur in alpaca pastures in the mid-Atlantic region, and that the presence of these beetles would likely enhance nutrient cycling and pasture growth. However, it is important to remember that dung beetles are just one component of many found in a healthy grassland ecosystem, and the functions of these components are interrelated.

DEDICATION

For my parents who raised me to have a strong appreciated for the land.

ACKNOWLEDGEMENTS

Thank you to everyone who had a hand in making this project happen from start to finish. I want to give special thanks to the people listed below.

Dr. Chris D. Teutsch
Dr. Stephan Wileus
Dr. A. Ozzie Abaye
Dr. D. Wesley Watson
Mac Tilson and Devin Rivers
Eric Day and Dr. Paul Semtner
The small ruminant crew at VSU
The faculty and staff of the Southern Piedmont AREC
Stephanie Arnold and Lindy Tucker
Judy Amos
Bob Polomsky, for making Figure 2.1 in thesis
USDA 1890 Institution Teaching, Research, and Extension Capacity Building Grant

TABLE OF CONTENTS

LIST OF TABLES

Chapter III

Chapter IV

LIST OF FIGURES

Chapter II

Chapter III

Chapter IV

CHAPTER I

Introduction

The alpaca fiber industry in the United States may be viable, with prices ranging from $70 to $110 per kg of fiber. The price depends on the quality, and animal nutrition is the most manageable factor influencing fiber quality. Unfortunately, nutritional recommendations for alpacas have been based on other small ruminants, and basic research on alpaca pasture management is lacking (Van Saun, 2006).

Continued volatility in fertilizer prices have been predicted by Park et al. (2010). In order for producers to remain profitable, they must isolate themselves from this volatility by adopting management practices that increase the efficiency of on-farm nutrient cycling. Soil organisms are an essential, yet often overlooked component of nutrient cycling. A better understanding of the activity of soil organisms to specific agroecosystems could help producers improve nutrient utilization for greater profitability.

Dung beetles are Coleopterans and are found in the Scarabaeidae and Geotrupidae families. As adults, they are attracted to vertebrate dung where they consume the liquid fractions. Eggs are laid in the dung and the emerging larvae feed on the more fibrous fraction before pupating in the soil or at the soil surface, depending on the species (Halffter and Edmonds, 1982). The brooding activities of dung beetles increase the decomposition rate of the dung, resulting in the various beneficial contributions to the ecosystem. Ecological contributions to the pasture ecosystem by dung beetles have been studied from numerous angles including pest and parasite control (Bornemissza, 1970; Bryan, 1973; Bryan, 1976; Waghorn et al., 2002; Chirico et al., 2003), nutrient cycling (Lindquist, 1933; Harris et al., 1980; Gittings et al., 1994; Bertone et al., 2006), and forage growth (Bornemissza and Williams, 1970; Fincher et al., 1981;

Bang et al., 2005; Yamada et al., 2007). These studies have primarily focused on the dung of cattle. Other livestock classes have received relatively little attention.

The objectives of this study were to describe the dung beetle community in alpaca pastures, and to evaluate the impact of dung beetle activity on soil nutrients and the growth of a common annual grass, using alpaca dung.

References

Bang, H.S., J.H. Lee, O.S. Kwon, Y.E. Na, Y.S. Jang, and W.H. Kim. 2005. Effects of paracoprid dung beetles (Coleoptera: Scarabaeidae) on the growth of pasture herbage and on underlying soil. Appl. Soil Ecol. 29:165-171.

Bertone, M.A., Green, J.T., Washburn, S.P., Poore, M.H., and Watson, D.W. 2006. The contribution of tunneling dung beetles to pasture soil nutrition. Forage and Grazinglands. doi: 10.1094/FG-2006-0711-02-RS.

Bornemissza, G.F. 1970. Insectary studies on the control of dung breeding flies by the activity of the dung beetle, *Onthophagus gazella* F. (Coleoptera: Scarabaeinae). J. Aust. Ent. Soc. 9:31-41.

Bornemissza, G.F. and C.H. Williams. 1970. An effect of dung beetle activity on plant yield. Pedobiologia. 10:1-7.

Bryan, R.P. 1973. The effects of dung beetle activity on the numbers of parasitic gastrointestinal helminth larvae recovered from pasture samples. Aust. J. Agric. Res. 24:161-168.

Bryan, R.P. 1976. The effect of the dung beetle, *Onthophagus gazella,* on the ecology of the infective larvae of gastrointestinal nematodes of cattle. Aust. J. Agric. Res. 27:567-564.

Chirico, J., S. Wiktelius, and P.J. Waller. 2003. Dung beetle activity and the development of trichostrongylid eggs into infective larvae in cattle faeces. Vet. Parasitol. 118:157-163.

Fincher, G.T., W.G. Monson, and G.W. Burton. 1981. Effects of cattle feces rapidly buried by dung beetles on yield and quality of coastal crabgrass. Agron. J. 73:775-779.

Gittings, T., P.S. Giller, and G. Stakelum. 1994. Dung decomposition in contrasting temperate pastures in relation to dung beetle and earthworm activity. Pedobiologia. 38:455-474.

Halffter, G. and W.D. Edmonds. 1982. The nesting behavior of dung beetles (Scarabaeinae): an ecological and evaluative approach. Instituto de Ecologia, A.C., Mexico, D.F.

Harris, R.L., E.H. Ilcken, R.R. Blume, and D.D. Oehler. 1980. The effects of horn fly larvae and dung beetles on ammonia loss from bovine dung. The Southwestern Entomol. 5(2):104-106.

Lindquist, A.W. 1933. Amounts of dung buried and soil excavated by certain Coprini (Scarabaeidae). J. Kansas Entomol. Soc. 6(4):109-125.

Park, T., M. Ahearn, T. Covey, K. Erickson, J. M. Harris, T. Kuethe, C. McGath, M. Morehart, A. Morton, S. Vogel, J. Weber, R. Williams, and S. Wozniak. 2010. Agricultural Income Finance Outlook. Pub. No. AIS-90. USDA Economic Research Service.

Van Saun, R.J. 2006. Nutrient requirements of South American camelids: A factorial approach. Small Rum. Res. 61:165-186.

Waghorn, T.S., D.M. Leathwick, L.Y. Chen, R.A.J. Gray, and R.A. Skipp. 2002. Influence of nematophagous fungi, earthworms and dung burial on development of the free-living stages of *Ostertagia (Teladorsagia) circumcincta* in New Zealand. Vet. Parasitol. 104:119-129.

Yamada, D., O. Imura, K. Shi, and T. Shibuya. 2007. Effect of tunneler dung beetles on cattle dung decomposition, soil nutrients and herbage growth. Japanese Soc. Grassland Sci. 53:121-129.

CHAPTER II

Literature Review

ALPACAS

Alpacas have been gaining prominence in grazing systems in the United States over the past few decades. According to Alpaca Registry, Inc. (2011), Virginia has 7,868 registered alpacas, the eighth largest alpaca population in the nation. As the alpaca population and popularity grows, the focus continues to be on breeding stock. Fiber production may be a viable industry if animal prices become more affordable. Fiber prices range from $70 to $110 per kg depending on color and quality. A single animal produces between 1 and 5 kg of fleece each year. Many factors impact fiber production and quality. Unfortunately, most management recommendations for these animals are based on other small ruminants such as goats and sheep, and the studies involving alpacas have been conducted in cooler climates. Among the factors that impact fiber growth and quality, nutrition is the most manageable.

Nutritional Requirements

Alpacas (*Vicugna pacos* L.) are camelid ruminants native to the South American Andes. Along with the llama, guanaco and vicuna, alpacas are often referred to as South American Camelids (SAC). They are within the infraorder Tylopoda because they have three stomach compartments rather than the four found in other ruminants. The stomach morphology and physiology of alpacas makes them well adapted to digest the low quality (low protein, high structural carbohydrate) forage of their native range (San Martin, 1987; Van Saun, 2006). Nutrient recommendations for SAC have largely been based on requirements of other ruminants. Huasasquiche (1974) determined the N requirement of alpacas to be 2.38 g kg^{-1} $BW^{0.75}$, which is lower than that of sheep (2.79 g kg^{-1} $BW^{0.75}$). Recently, Van Saun (2006) attempted to create models to make alpaca-specific nutrient requirements, and recommends standards be set by the National Research Council (NRC) as they have for goats and sheep. Maintenance energy (ME) for SAC in North America was determined to be around 72.85 kcal ME kg^{-1} $BW^{0.75}$, but would be higher for pregnant or lactating animals. Acid detergent fiber (ADF) and neutral detergent fiber (NDF) values of feed for camelids should be no less than 21-25% and 30-35%, respectively. The ADF and NDF values of vegetative pasture forage in the mid-Atlantic fulfill this recommendation, and generally range from 25-40% ADF and 45-65% NDF (Ball et al., 2002). Additional nutritional recommendations will continue to be based on other ruminants until further species-specific research is done. Sponheimer et al. (2003) is in agreement with past studies that have shown SAC to have higher digestive efficiency than true ruminants when consuming low quality feeds. Alpacas and llamas had higher digestive efficiency than goats on lower quality C4 grasses, but were similar when consuming C3 grasses with more digestible structural carbohydrates. Von Engelhardt and Schneider (1977) studied potential reasons for the low nutritional requirements of alpacas. They found that alpacas have more efficient urea recycling than sheep and goats, resulting in more N for microbe synthesis and an overall low basal metabolism for low energy requirements. Another reason for the efficiency in alpaca digestion may be tied to longer retention time in the rumen as well as a different ratio of salivary flow to the forestomach size (San Martin, 1987). Sponheimer et al. (2003) supports this conclusion, showing mean retention time for llamas and alpacas to be greater than that of goats, even when consuming improved forages.

Grazing Behavior and Diet Selection

Alpacas are adapted to grazing the relatively poor quality forages of the Andean range. Forage quality and availability drastically changes throughout the year with a rainy season followed by a 4-month dry season. As a result, alpacas are opportunistic grazers, consuming the forage that is abundant in a given season (Reiner and Bryant, 1986). On lower altitude pastures where forage quality is higher, alpacas selected forages first based on nutritional quality and secondly based on availability (Castellaro et al., 2007). Time spent grazing also varies by forage availability as a function of climate and altitude. More time is spent grazing and walking to find food in highlands than in lowlands, where forage availability is higher, to satisfy nutritional requirements (Reiner et al., 1987). Time spent at feeding stations is also shorter with increased forage availability in the wet season (Pfister et al., 1989). When compared to sheep, SAC exhibit a lower tendency to selectively graze, regardless of forage quality and management (San Martin et al., 1982; Sharp et al., 1995), with llamas being even less selective than alpacas (San Martin, 1987). On pasture consisting of grasses and legumes, San Martin (1987) saw a much higher preference for legumes in sheep than in alpacas or llamas. Because consumption of large amounts of legumes can result in bloat, bloat seems to be less of a problem for SAC.

Sharp et al. (1995) observed the grazing behavior of alpacas and sheep on improved New Zealand pastures and noted that the total time spent on various activities did not differ between species. However, the alpacas' grazing and ruminating events were more concentrated and occurred at different times in the day than the sheep. The alpacas also grazed more as a group, tended to be patchy grazers, and had group dunging areas. There is evidence that mixed grazing of SAC with sheep may increase forage utilization with each species occupying different grazing niches (Genin et al., 1994; Sharp et al., 1995).

Forage Intake

Due to digestive efficiency and longer mean retention time, SAC have lower dry matter intake compared to other ruminants. The lower particulate passage rates in SAC are negatively correlated with intake (San Martin, 1987). In a summary of past studies with alpacas on pasture, the average dry matter intake was 1.8% of their body weight, which was 20% lower than the average for sheep (San Martin and Bryant, 1989). Most previous studies involved alpacas grazing their native Andean range, but a recent Chinese study saw alpaca intake to be 40% lower than sheep intake on improved forages of alfalfa and sorghum-sudan (Liu et al., 2009). In taking fecal collections, Reiner et al. (1987) determined that seasonal climatic changes greatly affect organic matter intake of alpacas in the Andes where forage quality is significantly higher in the wet season than in the dry season. López et al. (1998) noted that alpaca intake was related to forage quality with higher digestibility and lower lignin content increasing intake. This conflicts with results from Reiner et al. (1987) where organic matter intake was higher on the low quality forage of the dry season than on the higher quality wet season forage. This was attributed to caloric and energy needs being met with lower intake of wet season forages because of the higher digestibility. Based on intake, the Peruvian Ministry of Agriculture has set the alpaca stocking rate to be 0.67 alpacas per sheep when sheep stocking rate is known. This estimate may be different in more controlled grazing situations where higher quality forages are being consumed.

Fiber Quality Factors

Domestication of alpacas has been primarily for fiber production. Many factors contribute to variations in fiber production and quality in fiber-producing animals. Measurements of fiber quality include fiber diameter, crimping, fiber strength, and curvature, with fiber diameter being the most economically important. In alpacas, fiber quality decreases with animal age as the mean fiber diameter increases (McGregor and Butler, 2004; Lupton et al., 2006; Jiang et al., 2008). Similar results were seen in a study with llamas by Iñiguez et al. (1998) where mean fiber diameters were greatest in older animals. Sheep wool quality measurements including fineness and the number of follicles are often genetically dependent (Visser, 1985). Llama fiber quality differences based on fiber diameter have also been attributed to breeding (Iñiguez et al., 1998; Coates and Ayerza, 2004). Recent studies by Prescuittini et al. (2010) and Allain and Renieri (2010) have looked at locating the genes responsible for certain fiber traits that may be economically desirable. Understanding the genetics of fleece phenotypes may improve breeding programs and increase the efficiency and profitability of fiber producing animals. Sex has been shown to be a significant factor in fiber production and quality in alpacas (Jiang et al., 2008; Castellaro et al., 1998, Lupton et al., 2006), with males having greater stable strength, while sex had no significant effect in a study conducted by McGregor and Butler (2004). While many of these factors are impossible to manage, nutrition can be managed to affect fiber productivity and quality in fiber-producing animals.

Fiber Quality and Liveweight

Nutrition has been primarily measured by liveweight and weight changes in studies related to alpaca fiber growth and quality. When compared to fiber growth and diameter of

Merino sheep, alpacas were more affected by low nutritional availability and weight loss (McGregor, 2002). Alpacas maintained at a high (2x maintenance requirement) quality diet had more fiber production including longer staple length and larger diameter than those fed a low (0.67x maintenance requirement) quality diet (Russel and Redden, 1997). Jiang et al. (2008) attributed fiber production differences to variations in management and nutrition. Specific nutrients and management techniques that may contribute to fiber differences have not been examined in alpacas.

Fiber Quality and Nutrition of Sheep and Goats

Nutritional impacts on fiber production and quality of sheep and Angora goats have received more attention. Amino acids, copper, zinc, folic acid, and pyridoxine influence wool growth, while the energy requirement for fiber production is low (Visser, 1985; Reis and Sahlu, 1994). Deaville and Galbraith (1992) and Masters et al. (1998) found that increasing protein rates increased the yield and diameter of fiber in Angora goats and sheep, respectively. The source of protein supplement may affect the growth of wool, but the quality is not significantly impacted (Masters et al. 1998; Habib et al., 2001). There is limited information on these factors in regard to alpacas. Therefore many recommendations including management practices that promote high fiber quality are based on other ruminants.

NUTRIENT CYCLING IN PASTURES

Soil fertility is an important consideration in the sustainability and profitability of agricultural systems. Commercial fertilizers are commonly added to maintain adequate soil nutrient levels, and this has been affordable for decades. The affordability has led to a reliance on these fertilizer inputs, and farmers are financially susceptible to changes in the market. Over the past decade fertilizer prices have dramatically increased. Park et al. (2010) of the USDA reported a 134 percent increase in fertilizer costs between 2002 and 2008, and predicted an additional 24 percent cost increase for 2011. The volatility of fertilizer prices makes it difficult for farmers to rely on off-farm fertilizer sources to the extent they could have a decade ago. Management practices that increase the efficiency of nutrient use and cycling on farms are essential for the future profitability of ruminant livestock producers.

Nutrient Pools and Transfers

Grazing animals make pasture ecosystems unique when compared to other agroecosystems. The pasture ecosystem is relatively closed, though nutrients may be imported in the form of hay, feed and mineral supplements and commercial fertilizers, or exported as hay, animal product and manure (West and Nelson, 2003). Balancing inputs and outputs of nutrients is important for both forage and animal health. Wedin and Russelle (2007) define the five nutrient pools in pasture ecosystems as 1) soil organic matter (the largest N pool other than the atmosphere), 2) living plant matter, 3) plant residue, 4) living animals including grazing animals, invertebrates and microbes, and 5) plant-available nutrient forms. In the basic cycle, grazing animals capture solar energy from plants and excrete waste onto the soil where it is decomposed and reabsorbed by plants. Many factors affect the rate of nutrient transport between pools including soil physical and chemical properties, plant species, and climate. Grazing animals increase the rate of nutrient transfer and recycling. Roquette et al. (1973) found that increasing the stocking rate increased the rate of nutrient cycling and nutrient retention in the system. The increase in removal of nutrients in the form of animal product with the higher stocking rate was outweighed by the improved forage utilization, resulting in more efficient cycling of existing nutrients and a decrease in need for off-farm nutrient inputs. A large percentage of nutrients consumed by grazing animals are returned to the soil in the form of manure and urine. For example, grazing animals excrete 75-85% of the forage they consume, only utilizing approximately 15-25% of the N, 20-26% of the P, and 15% of the K they consume (Bellows, 2001; West and Nelson, 2003). Manure is a good source of organic matter and consists mainly of degraded plant materials and contains bacteria and other microbes from the rumen along with their byproducts. Compared to commercial fertilizers, the release of nutrients in manure is relatively slow, and what is not available to plants in the first year is tied up as slowly degrading organic matter (Brady, 1990). Soil organic matter includes humus, readily degradable litter and waste, and living organisms. Insects, earthworms, fungi, bacteria, algae, protozoa, and nematodes are important soil organisms. Diversity of soil organisms is essential for nutrient cycling and soil aggregation (Bellows, 2001). Urine is a more readily available source of nutrients than manure as it contains water soluble nutrients such as N, S, and monovalent cations (Whitehead, 2000).

Nitrogen Cycle

With adequate rainfall the most limiting factor to plant productivity is nitrogen (N). Plants take up N in the form of ammonium (NH_4^+) and nitrate (NO_3^-). Along with carbon, plants utilize N to make proteins and nucleic acids for growth. Nitrogen increases dry matter yield, protein concentration, and leafy growth in forage plants (Noller and Rhykerd, 1974). In a bermudagrass study, Webster et al. (1965) found that N fertilization reduces structural carbohydrates, increasing digestibility. As mentioned previously, much of the N consumed by grazing animals is excreted. The primary form of N excreted by animals is urea (60-80% of the excreted N) in the urine (West and Nelson, 2003). Carbon and N are also returned to the soil by decomposing plant debris where it can be mineralized into plant available forms (NH_4^+ and NO_3^-) by microorganisms. Annual dieback of roots is 20-50%. In the decomposition process, animal and plant waste is converted to dissolved organic N before microbes mineralize the N into plant available forms. In this process some N is lost to ammonia volatilization, nitrate leaching, and denitrification (Allison, 1966; West and Nelson, 2003). In the mineralization process, microbes use dissolved organic N as an energy source and respire CO_2 with ammonium as a byproduct. Then, nitrifying bacteria use ammonium as an energy source and there is an anaerobic conversion to nitrate. The C:N ratio of the decomposing material is important for determining if net mineralization or immobilization will occur. A C:N ratio below 25-35 will result in net mineralization (Wedin and Russelle, 2007). When nutrients are immobilized, they are incorporated into the bodies of the soil organisms and are unavailable for plant uptake. In legumes, dinitrogen (N_2) from the atmosphere is fixed into a plant available form through a symbiotic relationship formed between the legume roots and Rhizobium bacteria (Wedin and Russelle, 2007). This relationship directly supplies N to the legumes, but transfer of fixed N to other forage species occurs primarily through decomposition of legume roots, nodules and above ground herbage, and through consumption and waste excretion of legume plants by grazing animals (Wedin and Russelle, 2007).

Phosphorus Cycle

Phosphorus is also an essential nutrient that grazing animals recycle in pasture ecosystems. With no atmospheric pool of P, the main source of P is rock weathering. The primary plant available form is phosphate (PO_4^{3-}), and is needed for energy transformation and growth. Animals consume P in herbage and excrete P primarily in the form of manure (Whitehead, 2000). Losses of both N and P are relatively low in grassland ecosystems compared to other cropping systems. Phosphorus is often bound to soil particles or in manure, so erosion and runoff lead to P loss (Bellows, 2001), but low solubility makes leaching minimal. The solubility of P is highly pH dependent. Phosphorus is most plant available at a pH of 6.5 to 7.5 (Fig. 2-1). At low pH, phosphate binds with Al, Fe, and Mn oxides and precipitates, while at high pH, it binds with Ca. When phosphate precipitates it becomes unavailable to plants (Wedin and Russelle, 2007).

Potassium Cycle

Along with N and P, K is regularly applied as fertilizer in grassland systems. It is essential for the transport of nutrients through the xylem as well as for regulation of physiological activities in plants (Whitehead, 2000). Yield and quality increases in forage plants are often seen with K fertilization. In soils, K is slowly made available through the weathering of clay minerals and through the decay of organic materials (Whitehead, 2000; Snyder and Leep, 2006). Potassium is plant available when it is in the ionic form (K^+) on the cation exchange site or in the soil solution (Snyder and Leep, 2006). Animals consume K in herbage and excrete it primarily in urine, though it also exists in smaller amounts in manure (Mott, 1974). The spatial distribution of dung and urine across the pasture greatly influences the cycling of nutrients within the pasture ecosystem.

Dung and Nutrient Distribution

With grazing cattle, higher concentrations of dung and urine are found near water, shade, and fence lines (Peterson et al., 1956; Marsh and Campling, 1970; White et al., 2001). The density of excretions across the remaining pasture is very low in comparison. Density varies by grazing time, number of animals, and pasture size. Increasing grazing intensity can improve the evenness of excretion distribution in pastures (Peterson et al., 1956). In contrast to cattle dunging behavior, alpacas establish communal dunging areas and will avoid grazing herbage in these latrine areas (McGregor, 2002). There are several approaches to managing the uneven nutrient distribution and loss of grazing area due to this behavior. Managers can relocate latrine sites by placing dung in more suitable locations to establish new dunging areas (McGregor and Brown, 2010). Grazing management approaches include co-grazing alpacas with sheep or cattle to improve nutrient distribution and forage utilization (McGregor, 2002). Increasing the stocking density of alpacas to encourage grazing in latrine areas may also be effective (McGregor and Brown, 2010).

Pasture Fouling

Uneven dung distribution patterns lead to accumulation of dung and pasture fouling (Fincher, 1981). Fouling of herbage by manure results in loss of potential grazing area. With cattle, a single animal fouls an average of 0.8-1.0 m^2 of herbage with dung daily (Bornemissza, 1960; Fincher, 1981), and fouling of these areas encourages weed growth, causing further refusal and loss of grazing area when dung is not rapidly disintegrated (Bornemissza, 1960). Bornemissza (1960) estimated that with an average of 10 dung events each day for cattle, 305 m^2 are fouled each year by one animal. This is equivalent to 3.1% of a hectare covered by dung by each animal in a year. Where dung-decomposing organisms such as dung beetles are absent or exist in low populations, dung accumulates in pastures (Bornemissza, 1960).

DUNG BEETLES

Resource Selection and Preference

The majority of dung beetles are opportunistic feeders of dung though few are species specific. Resource selection and preference often varies by the needs of dung beetle species. For example, beetles that lay their eggs within the dung will not lay them in wet portions, but in the crust if the dung is overly wet. Gittings and Giller (1998) outline 'findability', physical suitability, and nutritional quality as three factors that influence the colonization of dung resources. All of these are greatly affected by the stage of dung decomposition and desiccation. Dung beetles locate dung resources by detecting the volatile compounds emitted by dung (Dormont et al., 2007). Although olfactometer bioassays have shown that dung beetles are attracted to dung volatiles, the specific compounds have not yet been studied. Interestingly, the dung source during larval development appears to have no influence on adult olfactory preference for dung type (Dormont et al., 2010). Physical factors were studied by Al-Houty and Al-Musalam (1997) who noted preference for moist horse dung over that of dryer sheep and camel dung by *Scarabaeus cristatus* Fab in Kuwait. When comparing cow, horse and sheep dung of the same size, Finn and Giller (2002) found a higher abundance of beetles (primarily dweller type) in sheep dung than the other available dung resources. Dung resource abundance and grazing intensity have been shown to be factors in the composition of dung beetle communities in semi-arid regions of Spain (Lobo et al., 2006). The moisture of the soil also impacts the effectiveness of brood ball production (Barkhouse and Ridsdill-Smith, 1986).

As might be expected, climate plays a key role in composition of dung beetle assemblages (Errouissi et al., 2004). The same study supports conclusions that dung size and origin are also important factors. Because alpaca dung quality factors such as moisture content, consistency and N content vary from that of cattle dung, preference and resource selection may differ. Therefore, it is important to quantify and describe the abundance and community composition of dung beetles found in alpaca pastures in the mid-Atlantic region of the U.S.

Nesting Behavior

Dung beetles were categorized into three distinct niches based on their nesting behavior by Halffter and Edmonds (1982). Endocoprid beetles are known as "dwellers" as they lay their eggs and nest in the dung or just at the soil-dung interface. Paracoprid beetles are "tunnelers" that burrow down into the soil and excavate nesting chambers underneath the dung source. These beetles make brood balls that are generally sausage shaped which are food sources for the larvae that develop inside them. The telecoprid types are known as "rollers" and they too form brood balls for their larvae to consume. They differ from the paracoprid beetles in that a ball shaped allotment of dung is rolled away from the initial source and shallowly buried in the soil with a single egg laid on it (Fig. 2-2).

Benefits to Pasture Ecosystems

Contribution to dung removal and disintegration. While all three beetle types contribute to dung removal and subsequent pasture benefits, tunnelers probably contribute the most due to the excavating activity and sheer abundance. Adult dung beetles arrive at dung for liquid food resource and leave when liquid has been depleted by desiccation (Halffter and Matthews, 1966).

The first studies on their potential benefits were conducted in 1933 by Lindquist in Kansas where burrows were mapped and buried dung mass was recorded. Contribution of soil brought to the surface and dung buried in the soil varied by dung beetle species with larger species burying more than smaller. At a population density of 81 burrows ha^{-1}, the largest North American dung beetle, *Pinotus (Dichotomius) carolinus* L. was estimated to bury around 9.5 kg dry dung and excavate 25.9 kg soil. Similar work was done by MacQueen and Beirne (1975) who saw 37% dung burial and Hunt and Simmons (2002) who found that a single pair of *Onthophagus taurus* Schreber beetles could bury 36.8 g dung. Ferrar (1975) noted a three-fold increase in dung disintegration time with dung beetles.

When dung was freely exposed to organisms including flies, dung beetles, and earthworms, 20-25% of the organic matter had been removed in 11-14 days (Holter, 1979). The same study determined that earthworms were responsible for 50% of the dung removed while *Aphodius* species contributed to 14-20% of the removal. Earthworms are late arriving colonizers of dung and are able to mechanically fragment and consume the outer crust of dung, which deters natural weathering when intact. Maggots have little effect on dung fragmentation as shown by Lussenhop et al. (1980) where dung pats without dung beetles had a tough crust even when maggots were present, while dung with beetles was fragmented. Dung exposed to *Aphodius* species alone had less dung beetle activity and higher moisture content than dung exposed to all arthropods over a 24-hour period (Stevenson and Dindal, 1987). In the freely exposed dung treatments, burrowing tunneling dung beetle species increased the rate of desiccation by increasing aeration and redox potential (Eh) of the dung. Dung in these treatments also had higher dung beetle population densities than the *Aphodius* treatments, which increased the decomposition rate. While dweller type dung beetles assist in fragmentation and shredding of dung, they do not play as important a role in decomposition and dung removal as tunnelers.

Interactions of dung-decomposing organisms. Dung beetles are not the only important organisms involved in dung decomposition. Holter (1979) and Gittings et al. (1994) both determined that earthworms were most directly and indirectly responsible for dung removal where endocoprid *Aphodius* beetles were the prominent dung beetle species. Interestingly, when *Aphodius* larvae were added to dung pats under gauze tents, earthworm immigration increased compared to pats excluded from beetles and flies. This lead to the conclusion that late arriving dung colonizers like earthworms are dependent on the early arrivers (Holter, 1979). Holter (1983) later concluded that ammonia release might be the trigger for earthworm aggregation in dung pats. Not only does dung beetle activity affect earthworm aggregation, it also has been seen to affect bacterial and fungal populations. Natural activity from maggots and adult *Aphodius* beetles created conditions favorable for bacterial growth over fungi in dung pats by giving bacteria a continuous fresh supply of substrate by mixing the dung. The same mixing activity was seen to hinder the ability of fungi to expand (Lussenhop et al. 1980). Opposite effects on fungal and bacterial populations were seen in Yokoyama et al. (1991a) with the activity of *Onthophagus lenzii*. Dung decomposition by microorganisms alone is relatively slow, but burial of dung by dung beetles stimulates soil microbes for improved soil conditions for plant growth (Holter, 1979).

Contributions to pest control. Dung burial and disintegration by dung beetles has been studied as a means of pest and parasite control due to disturbance of larval habitat. Results on internal parasite control are varied. Bornemissza (1960), Fincher (1975), Bryan (1976), and Gormally (1993) all saw reductions in the various parasite larvae of focus in dung with dung beetles while Chirico (2003) found that in reducing the moisture content of the dung, dweller type beetles actually improve the habitat for trichostrongylid larvae that prefer a drier environment for development. Herbage surrounding dung buried by researchers (not dung beetles) had an increased number of gastrointestinal nematode larvae over herbage where dung was unburied (Waghorn et al., 2002). Parasitic gastrointestinal helminth larvae require a moisture film to migrate from the dung to herbage where they are consumed by livestock. In a study by Bryan (1973), dung beetles were able to desiccate the dung and deter the migration of helminth larvae to the herbage. However, when these plots were irrigated the impact of the dung beetles was not noticeable. Some of the varied results may be attributed to climate differences as noted by Bryan (1973). Pestiferous fly control by dung beetles was originally proposed by Fullaway (1921) in Hawaii where dung beetles were introduced for horn fly control. More recently, Bornemissza (1970) introduced dung beetles to Australia and found reduced bush fly (*Musca vetustissima* Walker) larvae when dung was buried by *Onthophagus gazella* beetles. By diminishing the food source, the dung beetles caused premature pupation and emergence of flies in beetle treatments occurred 24-30 hours before controls. Those that emerged were clearly smaller and some died in the puparium, while fly maggot development had no detrimental effect on the development of beetle larvae or on the size of emerging adults.

Nutrient cycling enhanced by dung beetles. Research has also shown that nutrient cycling is enhanced with dung beetle activity. Nitrogen losses from volatilization in cattle pastures may be reduced by up to 15% with dung burial, and 80-95% of the N in the dung may be buried by more vigorous dung beetles (Gillard, 1967). Harris et al. (1980) found that *Onthophagus gazella* beetles significantly lowered the ammonia loss form dung, though the results varied with airflow rate. Yokoyama et al. (1991b) also saw lowered ammonia volatilization with 2 pairs of *Onthophagus lenzi*. A related study by Yokoyama et al. (1991c) noticed a shift in N transformation from net immobilization to mineralization with aerobic conditions created by dung beetles in residual dung and in dung balls. Dung beetle activity also caused an accumulation of readily mineralizable hydrolysable ammonium in residual dung and dung balls. Activity from all dung beetle types incorporates organic matter into the topsoil, increasing soil carbon and nitrogen concentrations available for microbial mineralization and nitrification (Stevenson and Dindal, 1987 and Yokoyama et al., 1991a). In tunneling species, larvae do not eat all of the brood ball resource and some of what they do eat is returned as frass, the remains of which are available to microorganisms (Lindquist, 1933). Soil phosphorus (P), potassium (K), magnesium (Mg), cation exchange capacity (CEC) and pH are have been increased by tunneling dung beetles according to Bertone (2006), though the significance varied by soil type.

Impacts on soil physical properties. Soil physical properties improved by dung beetles have been studied to a lesser extent and more research is needed to explore these potential benefits further. Burrowing activity of tunneler species increase the mixing of mineral soil with organic matter, known as bioturbation (Mittal, 1993), and soil permeability can be increased with tunneling beetles in the top 10 cm of soil (Bang et al., 2001). When tunneler species construct their tunnels, the tunnel walls are packed with loose back-fill and soil is deposited on the soil surface during excavation. These tunnels have a diameter ranging from 1-50 mm, creating macropores for aeration and water infiltration (Halffter and Edmonds, 1982). The macropores created by the burrows results in preferential root growth in the tunnels (Brussaard and Hijdra, 1986). Edwards (1986) concluded that soil conditions play a role in the depth of tunneling with the moist soil enabling the digging of deeper tunnels when compared to dry soil. This is likely due to increased soil strength with drying. A recent South African study by Brown et al. (2010) found that when dung was naturally colonized in the field, infiltration was higher after 48 hours than dung without dung beetles. Also, the soil in this treatment was able to hold more water before running off and porosity increased in the topsoil, with lower bulk density in the upper 10 cm where major plant root development occurs. Organic matter buried in the topsoil contributed to a higher water holding capacity, and after 6 months, infiltration was improved down to 30 cm in the subsoil.

Role of dung beetles on forage growth. Increased nutrient cycling, increased organic matter incorporation, and improved soil physical properties due to dung beetle activity result in increased forage growth in cattle pastures. Bornemissza and Williams (1970) first researched this concept with a pot study using Japanese millet and the addition of 20 pairs of *Onthophagus australis.* A field study was conducted by Fincher et al. (1981) with coastal bermudagrass and 11 dung beetle species introduced under netting. A similar field study was conducted using mixed cool season pasture and 3 species of dung beetles along with a pot study (Bang et al., 2005). Lastro (2006) used 5 pairs of *Onthophagus taurus* in pot studies of both a cool season (annual ryegrass) and a warm season annual grass (Sudangrass). Most recently, Yamada et al. (2007) conducted a field study in an orchardgrass pasture comparing forage growth with 40, 80, or 120 tunneling dung beetles under netting. The results of all of these studies showed increased forage growth with dung beetle activity to various extents. Results varied by soil type and forage type, but an overall conclusion that dung beetle (primarily tunneling) activity increases forage growth can be drawn. All of these studies used cattle dung as the dung resource and research is needed to quantify potential benefits to forage growth in other ruminant livestock grazing systems.

CRABGRASS

Forage systems in Virginia are generally based on cool season forage, primarily consisting of tall fescue. Cool season forages are high yielding in the spring and have a second surge of growth in the fall. The limitation of this system is the inability to supply quality forage in the summer. Crabgrass (*Digitaria* species), a warm season annual grass, can provide high quality summer grazing in the mid-Atlantic region.

Crabgrass as a Forage

Crabgrass is a persistent warm season annual grass that is well adapted to the southern and southeastern United States, though its range includes all states other than Alaska. Ideal growing conditions for crabgrass include high rainfall, mild temperatures, and well drained soils with adequate fertility. Acidity as low as a pH value of 4.3 appears to have no significant effect on germination, shoot or root yield (Aleshire and Teutsch, 2005). Also, an effective drought tolerance mechanism allows it to efficiently utilize low levels of rainfall following periods of drought, which has become important in recent years in the mid-Atlantic (Teutsch et al., 2005a). It has been intentionally used as a forage crop in the United States since the mid 1800s, but use dropped off when it became a weed issue in other crops (Dalrymple, 1993). Crabgrass is often a volunteer species, but improved varieties have been developed and management strategies are being researched (Dalrymple, 1994).

Yield and Nutritional Quality

Proper management of crabgrass can result in yields and animal gains comparable or superior to other warm season grasses used in the mid-Atlantic. Dalrymple and Mitchell (1991) studied the effect of cutting height and growth stage on crabgrass yield to simulate rotational grazing management strategies. His results showed an increase in yield with increased residue and recovery time. Crabgrass also has a positive yield response to N fertilization. Past studies have seen 10-32 kg forage yield per kg of N applied with overall yields generally ranging from 4,370 to 10,000 kg ha^{-1} depending on N rate (Dalrymple, 1993, Teutsch et al., 2005b). Recommended seasonal N rate is between 150-250 kg ha^{-1}. Nitrogen fertilization affects yield and forage quality, and both must be considered when evaluating fertilization strategies for summer annual grasses (Fribourg, 1974). Plant available N is strongly correlated with crude protein (CP) in herbage (Olson and Kurtz, 1982), and this has been the case with crabgrass (Teutsch et al., 2005a). The CP concentrations average 12-16% in the summer, but may be up to 25% in the first harvest (Dalrymple, 1993; Dalrymple, 1994). Digestibility of crabgrass is generally better than bermudagrass and has a digestible dry matter (DDM) content of 41-80% depending on maturity (Dalrymple, 1994). In a Virginia study, NDF averaged 61% in the final harvest, which is lower than other summer annuals and bermudagrass under similar conditions (Teutsch et al., 2005b). When broiler litter was compared to ammonium nitrate as a N source for crabgrass, CP was higher in the first harvest with ammonium nitrate. This can be attributed to ammonium nitrate being more available to plants initially. Levels of NDF were not affected by nitrogen source (Teutsch, 2005a). More research is needed to evaluate the effect of grazing and natural nutrient cycling from animal waste on crabgrass yield and quality.

Animal performance of crabgrass has been huge. Daily gains of beef stocker steer and heifers averaged 0.68 kg per day per head with an average beef yield of 325 kg ha^{-1} in poor to moderate conditions in Oklahoma (Dalrymple, 1994). With proper management, the quality and palatability coupled with adaptability and persistence of crabgrass makes it a solid forage species for mid-Atlantic pastures.

SUMMARY AND RESEARCH OUTLOOK

Although alpacas have the ability to survive on low quality forage (San Martin, 1987; Van Saun, 2006), high quality forage may improve alpaca fiber growth and quality (Masters et al. 1998; McGregor, 2002). In the mid-Atlantic region of the U.S., high temperatures and intermittent rainfall limit cool-season grass growth during the summer. Crabgrass has the potential to supply ample and high quality forage for alpacas during this period.

Efficient nutrient cycling in grazing systems reduces the amount of off-farm inputs and optimizes the utilization of added nutrients. Understanding and managing for strong nutrient cycles is an essential component of profitable ruminant livestock operations. Dung beetles play an important role in strengthening nutrient cycles in grassland ecosystems. Past studies have shown increases in forage yield related to improvements in soil qualities with dung beetle activity, but these studies have almost solely focused on grazing systems for cattle. Limited data on the impact of dung beetles in grazing systems for small ruminants is available, and no data exist for camelids. Alpaca dung may provide suitable habitat for dung beetles. However, the benefits to the alpaca pasture ecosystem, especially on soil and forage nutritive quality, need to be quantified. Dung beetle activity on alpaca dung may enhance conditions for crabgrass growth, making it sufficient for alpaca maintenance.

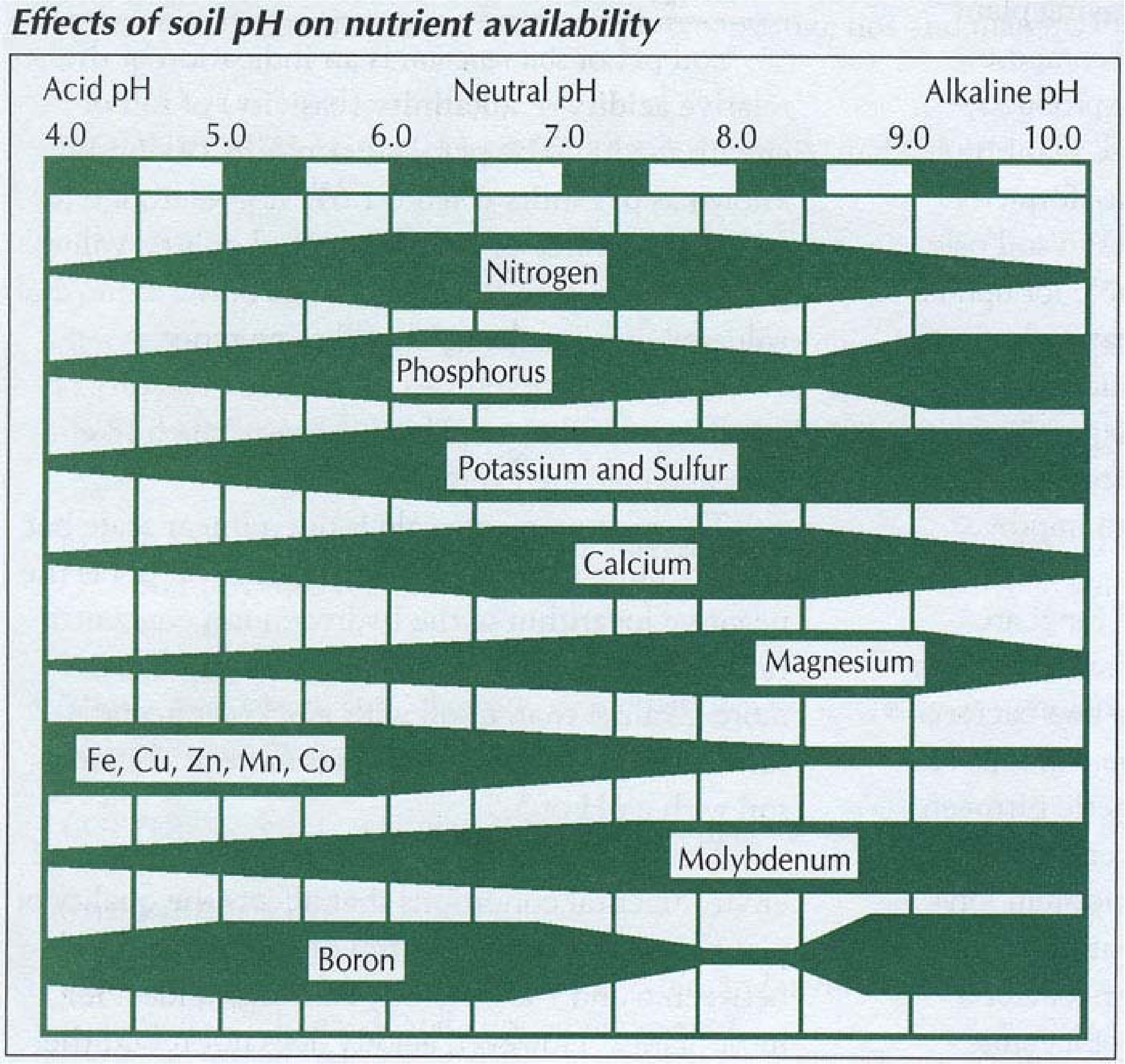


Figure 2-1. The relationship between plant availability of soil nutrients at different pH levels. Increasing width of the bars indicates increased plant availability (Polomsky, 2007). Used under Fair Use guidelines, 2012.

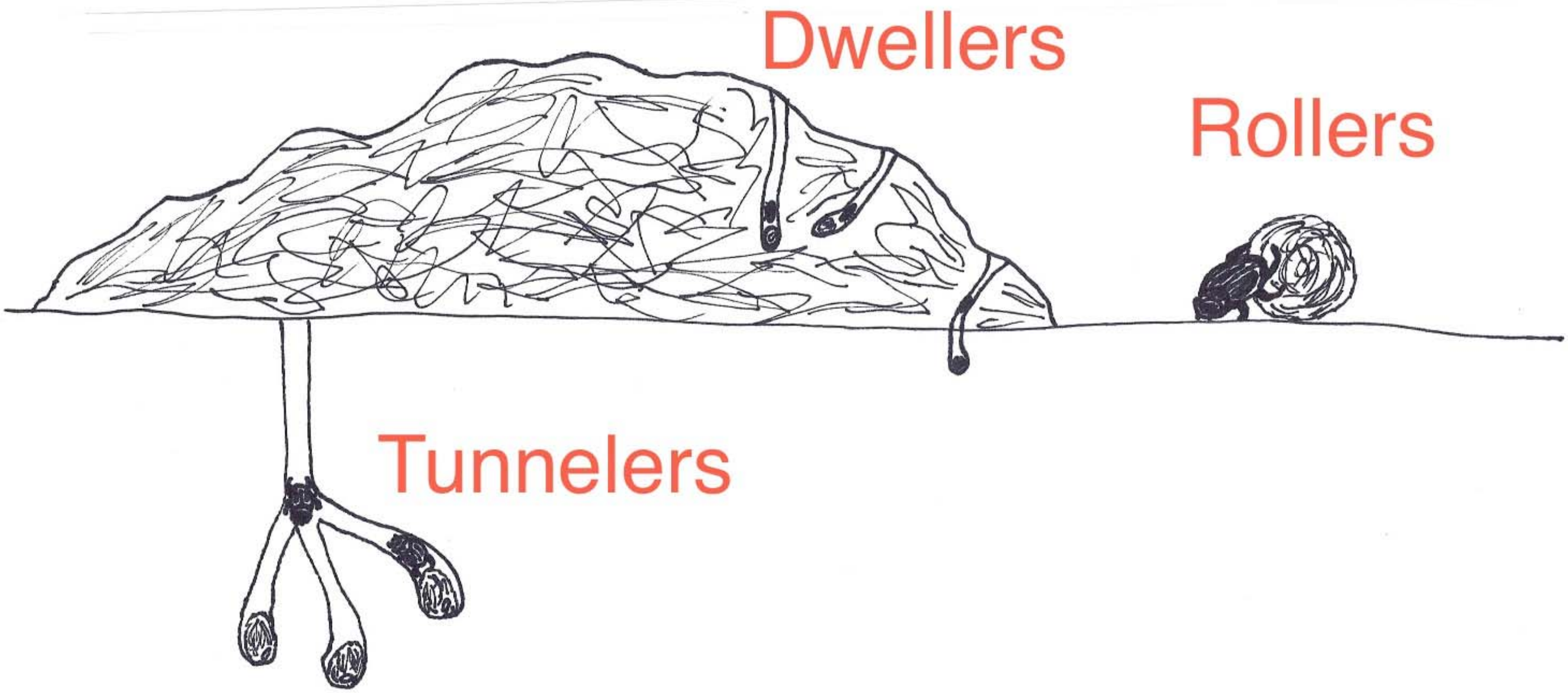


Figure 2-2. Diagram of the three nesting guilds of dung beetles (tunnelers, dwellers, rollers).

References

Aleshire, E.B. and C.D. Teutsch. 2005. Soil pH effects on the shoot and root yield of crabgrass. Forage and Grazinglands. doi: 10.1094/FG-2005-0714-01-RS.

Alpaca Registry, Inc. 2011. Registered Alpaca US. Online. Accessed 20 October 2011. http://www.alpacaregistry.com/public/reports/alpacaus.

Al-Houty, W. and F. Al-Musalam. 1997. Dung preference of the dung beetle *Scarabeaus cristatus* Fab (Coleoptera-Scarabaeidae) from Kuwait. J. Arid Environ. 35:511-516.

Allain, D. and C. Renieri. 2010. Genetics of fibre production and fleece characteristics in small ruminants, Angora rabbit and South American camelids. Animal 4(9):1472-1481.

Allison, F.E. 1966. The fate of nitrogen applied to soils. Adv. Agron. 18:219-258.

Ball, DM., C.S. Hoveland, and G.D. Lacefield. 2002. Southern forages, 3rd ed. Potash and Phosphate Institute and Foundation for Agronomic Research, Norcross, GA.

Bang, H.S., C. Huerta, J.I. Kim, and T.W. Goo. 2001. Studies on the ecology of oviposition of *Copris tripartitus* Waterhouse (Motschulsky) (Coleoptera: Scarabaeidae). Korean J. Ent. 31:237-242.

Bang, H.S., J.H. Lee, O.S. Kwon, Y.E. Na, Y.S. Jang, and W.H. Kim. 2005. Effects of paracoprid dung beetles (Coleoptera: Scarabaeidae) on the growth of pasture herbage and on underlying soil. Appl. Soil Ecol. 29:165-171.

Barkhouse, J. and T.J. Ridsdill-Smith. 1986. Effect of soil moisture on brood ball production by *Onthophagus binodis* Thunberg and *Euoniticellus intermedius* (Reiche) (Coleoptera: Scarabaeinae). J. Aust. Ent. Soc. 25: 5-78.

Bellows, B. 2001. Nutrient Cycling in Pastures. Available at https://attra.ncat.org/attra-pub/summaries/summary.php?pub=240 (verified 4 October 2011). ATTRA-NCAT, Butte, MT.

Bertone, M.A., Green, J.T., Washburn, S.P., Poore, M.H., and Watson, D.W. 2006. The contribution of tunneling dung beetles to pasture soil nutrition. Forage and Grazinglands. doi: 10.1094/FG-2006-0711-02-RS.

Bornemissza, G.F. 1960. Could dung eating insects improve our pastures? J. Australian Institute of Agric. Sci. 26:54-56.

Bornemissza, G.F. 1970. Insectary studies on the control of dung breeding flies by the activity of the dung beetle, *Onthophagus gazella* F. (Coleoptera: Scarabaeinae). J. Aust. Ent. Soc. 9:31-41.

Bornemissza, G.F. and C.H. Williams. 1970. An effect of dung beetle activity on plant yield. Pedobiologia 10:1-7.

Brady, N.C. 1990. The Nature and Properties of Soils. 10th ed. Macmillan Publishing Co., New York.

Bryan, R.P. 1973. The effects of dung beetle activity on the numbers of parasitic gastrointestinal helminth larvae recovered from pasture samples. Aust. J. Agric. Res. 24:161-168.

Bryan, R.P. 1976. The effect of the dung beetle, *Onthophagus gazella,* on the ecology of the infective larvae of gastrointestinal nematodes of cattle. Aust. J. Agric. Res. 27:567-564.

Brown, J. C.H. Scholtz, J.L. Janeau, S. Grellier, and P. Podwojewski. 2010. Dung beetles (Coleoptera: Scarabaeidae) can improve soil hydrological properties. Appl. Soil Ecol. 46:9-16.

Brussaard, L. and R.D.W. Hijdra. 1986. Some effects of scarab beetles in sandy soils of the Netherlands. Geoderma. 37:325-330.

Castellaro, G.G., P.J. García, and P. Salinas. 1998. Alpaca liveweight variations and fiber production in Mediterranean range of Chile. J. Range Manag. 51:509-513.

Castellaro, G.G., F.N. Squella, F.C. León, and A.S. Raggi, 2007. Botanical composition of alpaca (*Lama pacos* Linn.) diet in a Central Mediterranean range of Chile. Chilean J. of Agric. Res. 68:136-145.

Coates, W., and R. Ayerza. 2004. Comparison of llama fiber obtained from production regions of Argentina. J. of Arid Environ. 58:513-524.

Chirico, J., S. Wiktelius, and P.J. Waller. 2003. Dung beetle activity and the development of trichostrongylid eggs into infective larvae in cattle faeces. Vet. Parasitol. 118:157-163.

Dalrymple, R.L. 1993. Crabgrass for high quality, high production, warm season forage. Small Farm Today. 10(1):14-15.

Dalrymple, R.L. 1994. A summary of research and demonstration about using crabgrass as a forage. Pub. No. CG-83. Noble Foundation, Ardmore, OK.

Dalrymple, R.L., and Mitchell, R.L. 1991. Crabgrass forage yields as influenced by forage harvesting regimes. p. 221-224. *In* Proc. American Forage and Grasslands Conference, Columbia, MO.

Deaville, E.R., and H. Galbraith. 1992. Effect of dietary protein level and yeast culture on growth, blood prolactin and mohair fibre characteristics of British Angora goats. Anim. Feed Sci. and Technol. 38:123-133.

Dormont, L., S. Rapior, D.B. McKey, and J. Lumaret. 2007. Influence of dung volatiles on the process of resource selection by coprophagous beetles. Chemoecology 17:23-30.

Dormont, L., P. Jay-Robert, J.M. Bessiére, S. Rapior, and J.P. Lumaret. 2010. Innate olfactory preferences in dung beetles. J. Exp. Biol. 213:3177-3186.

Edwards, P.B. 1986. Phenology and field biology of the dung beetle *Onitis caffer* Boheman (Coleoptera: Scarabaeidae) in southern Africa. Bull. Entomol. Res. 76:433-446.

Errouissi, F., S. Haloti., P. Jay-Robert, A. Janati-Idrissi, and J. Lumaret. 2004. Effects of the attractiveness for dung beetles of dung pat origin and size along a climatic gradient. Commun. and Ecosys. Ecol. 33(1):45-53.

Ferrar, P. 1975. Disintegration of dung pads in North Queensland before the introduction of exotic dung beetles. Aust. J. Expt. Agric. Anim. Husb. 15:325-329.

Fincher, G.T. 1975. Effects of dung beetle activity on the number of nematode parasites acquired by grazing cattle. J. Parasitol. 61(4):759-762.

Fincher, G.T. 1981. The potential value of dung beetles in pasture ecosystems. J. Georgia Entomol. Soc. 16(2):316-333.

Fincher, G.T., W.G. Monson, and G.W. Burton. 1981. Effects of cattle feces rapidly buried by dung beetles on yield and quality of coastal crabgrass. Agron. J. 73:775-779.

Finn, J.A. and P.S. Giller. 2002. Experimental investigations of colonization by north temperate dung beetles of different types of domestic herbivore dung. Appl. Soil Ecol. 20:1-13.

Fribourg, H.A. 1974. Fertilization of Summer Annual Grasses and Silage Crops. p. 189-212. *In* D.A. Mays (ed) Forage Fertilization. ASA, CSSA, and SSSA, Madison, WI.

Fullaway, D.T. 1921. Horn fly control. Hawaii Forest. and Agric.18:219-221.

Genin, D., Z. Villca, and P. Abasto. 1994. Diet selection and utilization by llama and sheep in a high altitude-arid rangeland of Bolivia. J. Range Manag. 47(3):245-248.

Gillard, P. 1967. Coprophagous beetles in pasture ecosystems. J. Aust. Inst. Agric. Sci. 33:30-34.

Gittings, T., P.S. Giller, and G. Stakelum. 1994. Dung decomposition in contrasting temperate pastures in relation to dung beetle and earthworm activity. Pedobiol. 38:455-474.

Gittings, T. and P.S. Giller. 1998. Resource quality and the colonization and succession of coprophagous dung beetles. Ecography 21:581-592.

Gormally, M.J. 1993. The effect of dung beetle activity on the discharge of *Pilobulus sporangia* in cattle faeces. Med. Vet. Ent. 7(2): 197-198.

Habib, G., M.M. Siddiqui, F.H. Mian, J. Jabbar, and F. Khan. 2001. Effect of protein supplements of varying degradability on growth rate, wool yield and wool quality in grazing lambs. Small Rum. Res. 41:147-256.

Halffter, G. and E.G. Matthews. 1966. The natural history of dung beetles of the subfamily Scarabaeinae). Folia Entomol. Mexi. 12:14-312.

Halffter, G. and W.D. Edmonds. 1982. The nesting behavior of dung beetles (Scarabaeinae): an ecological and evaluative approach. Instituto de Ecologia, A.C., Mexico, D.F.

Harris, R.L., E.H. Ilcken, R.R. Blume, and D.D. Oehler. 1980. The effects of horn fly larvae and dung beetles on ammonia loss from bovine dung. The Southwestern Entomol. 5(2):104-106.

Holter, P. 1979. Effect of dung beetles (*Aphodius* spp.) and earthworms on the disappearance rate of cattle dung. Oikos 32:393-402.

Holter, P. 1983. Effect of earthworms on the disappearance of cattle droppings. p. 49-57. *In* Satchell, J.E. (ed.) Earthworm Ecology: From Darwin to Vermiculture. Chapman and Hall, London.

Huasasquiche, A. 1974. Nitrogen balance and digestibility in alpacas and sheep. B.S. Thesis. Univ. Nac. Mayor de San Marcos, Lima, Peru.

Hunt, J. and L.W. Simmons, 2002. Behavioural dynamics of biparental care in the dung beetle *Onthophagus taurus*. Anim. Behav. 64(1):65-75.

Iñiguez, L.C., R. Alem, A. Wauer, and J. Mueller. 1998. Fleece types, fiber characteristics and production system of an outstanding llama population from Southern Bolivia. Small Rum. Res. 30:57-65.

Jiang, J., J. He, C. Dong, and K. Dong. 2008. Fiber performance of introduced Huacaya alpacas grazing on sown pasture. Acta Agrestia Sinica. 16(3):245-250.

Lastro, E. 2006. Dung beetles (Coleoptera: Scarabaeidae and Geotrupidae) in North Carolina Pasture Ecosystems. M.S. Thesis. North Carolina State Univ., Raleigh, North Carolina.

Lindquist, A.W. 1933. Amounts of dung buried and soil excavated by certain Coprini (Scarabaeidae). J. Kansas Entomol. Soc. 6(4):109-125.

Liu, Q., C.S. Dong, H.Q. Li, W.Z. Yang, J.B. Jiang, W.J. Gao, C.X. Pei, and Z.Q. Liang. 2009. Forestomach fermentation characteristics and diet digestibility in alpacas (*Lama pacos*) and sheep (*Ovis aries*) fed two forage diets. Anim. Feed Sci. Technol. 154:151-159.

Lobo, J.M., J. Hortal, and F.J. Cabrero-Sanudo. 2006. Regional and local influence of grazing activity on the diversity of a semi-arid dung beetle community. Divers. Distrib. 12:111-123.

López, A., J. Maiztegui, and R. Cabrera. 1998. Voluntary intake and digestibility of forages with different nutritional quality in alpacas (*Lama pacos*). Small Rum. Res. 29:295-301.

Lupton, C.J., A. MColl, and R.H. Stobart. 2006. Fiber characteristics of the Huacaya Alpaca. Small Rum. Res. 64:211-224.

Lussenhop, J., R. Kumar, D.T. Wicklow, and J.E. Lloyd. 1980. Insect effects on bacteria and fungi in cattle dung. Oikos 34:54-58.

Macqueen, A. and B.P. Beirne. 1975. Effects of cattle dung and dung beetle activity on growth of beardless wheatgrass in British Columbia. Can J. Plant Sci. 55:961-967.

Marsh, R. and R.C. Campling. 1970. Fouling of pastures by dung. Herb. Abstr. 40(2):123-130.

Masters, D.G., G. Mata, S.M. Liu, and A.D. Peterson. 1998. Influence of liveweight, liveweight change, and diet on wool growth, staple strength, and fibre diameter in young sheep. Aust. J. Agric. Res. 49:269-277.

McGregor, B.A. 2002. Comparative productivity and grazing behaviour of Huacaya alpacas and Peppin Merino sheep grazed on annual pastures. Small Rum. Res. 44:219-232.

McGregor, B.A. and K.L. Butler. 2004. Sources of variation in fibre diameter attributes of Australian alpacas and implications for fleece evaluation and animal selection. Austr. J. Agric. Res. 55:433-442.

McGregor, B.A. and A.J. Brown. 2010. Soil nutrient accumulation in alpaca latrine sites. Small Rum. Res. 94:17-24.

Mittal, I.C. 1993. Natural manuring and soil conditioning my dung beetles. Trop. Ecol. 34:150-159.

Mott, G.O. 1974. Nutrient Recycling in Pastures. p. 323-339. *In* D.A. Mays (ed.) Forage Fertilization. ASA, CSSA, and SSSA, Madison, WI.

Noller, C.H. and C.L. Rhykerd. 1974. Relationship of Nitrogen Fertilization and Chemical Composition of Forage to Animal Health and Performance. p. 363-394. *In* D.A. Mays (ed.) Forage Fertilization. ASA, CSSA, and SSSA, Madison, WI.

Olson, R.A. and L.T. Kurtz. 1982. Crop nitrogen requirements, utilization, and fertilization. p. 567-604. *In* F.J. Stevenson (ed.) Nitrogen in agricultural soils. Agron. Mongr. 22. ASA, CSSA, and SSSA, Madison, WI.

Park, T., M. Ahearn, T. Covey, K. Erickson, J. M. Harris, T. Kuethe, C. McGath, M. Morehart, A. Morton, S. Vogel, J. Weber, R. Williams, and S. Wozniak. 2010. Agricultural Income Finance Outlook. Pub. No. AIS-90. USDA Economic Research Service.

Peterson, R.G., W.W. Woodhouse, Jr., and H.L. Lucas. 1956. The distribution of excreta by freely grazing cattle and its effect on pasture fertility: II. Effect of returned excreta on the residual concentration of some fertilizer elements. Agron. J. 10:444-449.

Pfister, J.A., F. San Martin, L. Rosales, D.V. Sisson, E. Flores, and F.C. Bryant. 1989. Grazing behaviour of llamas, alpacas and sheep in the Andes of Peru. Applied Anim. Behav. Sci. 23:237-246.

Polomski, R. 2007. The South Carolina Master Gardener Training Manual. Publication No. EC 678. Clemson University Cooperative Extension, Clemson SC.

Prescuittini, S., A. Valbonesi, N. Apaza, M. Antonini, T. Huanca, and C. Renieri. 2010. Fleece variation in alpaca (*Vicugna pacos):* a two-locus model for the Suri/Huacaya phenotype. BMC Genetics 11(70):1-8.

Reiner, R.J. and F.C. Bryant. 1986. Botanical composition and nutritional quality of alpaca diets in two Andean rangeland communities. J.Range Manag. 39:424-427.

Reiner, R.J., F.C. Bryant, R.D. Farfan, and B.G. Craddock. 1987. Forage intake of alpacas grazing Andean rangeland in Peru. J. Anim. Sci. 63:868-871.

Reis, P.J. and T. Sahlu. 1994. The nutritional control of the growth and properties of mohair and wool fibers: a comparative review. J. Anim. Sci. 72:1899-1907.

Roquette, F.M., Jr., J.E. Matocha, and R.L. Duble. 1973. Recycling and recovery of nitrogen, phosphorus, and potassium by coastal Bermudagrass: II. Under grazing conditions with two stocking rates. J. Environ. Qual. 2(1):129-132.

Russel, A.J.F. and H.L. Redden. 1997. The effect of nutrition on fibre growth in the alpaca. Anim. Sci. 64:509-512.

San Martin, F., A. Huasasquiche, R. Farfan, O. Del Valle, D. Holgado, R. Arbaiza, M. Nava, and C. Villarroel. 1982. Comparative intake and digestibility for alpacas and sheep of cultivated grasses during two seasons. Resumenes Proyectos Investigacion. Univ. Nac. Mayor de San Marcos, Lima. 1-2: 255.

San Martin, F. 1987. Comparative forage selectivity and nutrition of South American Camelids and sheep. Ph.D. diss. Texas Tech Univ., Lubbock, Texas.

San Marin, F. and F.C. Byrant. 1989. Nutrition of domesticated South American llamas and alpacas. Small Rum. Res. 2:191-216.

Sharp, P., T.W. Knight, and J. Hodgson. 1995. Grazing behaviour of alpaca and sheep. Proc. New Zealand Society of Animal Production 55:183-185.

Sponheimer, M., T. Robinson, B. Roeder, J. Hammer, L. Ayliffe, B. Passey, T. Cerling, D. Dearing, and J. Ehleringer. 2003. Digestion and passage rates of grass hays by llamas, alpacas, goats, rabbits, and horses. Small Rum. Res. 48:149-154.

Snyder, C.S. and R.H. Leep. 2006. Fertilization. p. 355-377. *In* R.F. Barnes et al. (ed.) Forages: The Science of Grassland Agriculture. vol. 2. 6th ed. Ames, IA: Blackwell Publishing Professional.

Stevenson, B.G. and D.L. Dindal. 1987. Insect effects on decomposition of cow dung in microcosms. Pedobiol. 30:81-92.

Teutsch, C.D., J.H. Fike, and W.M. Tilson. 2005a. Yield, digestibility, and nutritive value of crabgrass as impacted by nitrogen fertilization rate and source. Agron. J. 97:1640-1646.

Teutsch, C.D., J.H. Fike, and W.M. Tilson. 2005b. Nitrogen fertilization rate and application timing effects on the nutritive value and digestibility of crabgrass. Forage and Grazinglands. doi: 10.1094/FG-2005-0614-01-RS.

Van Saun, R.J. 2006. Nutrient requirements of South American camelids: A factorial approach. Small Rum. Res. 61:165-186.

Visser, D.J. 1985. Biological influences on the quality properties of wool. South African J. Anim. Sci. 15(3):123-127.

Von Engelhardt, W. and W. Schneider. 1977. Energy and nitrogen metabolism ini the llama. Anim. Res. Dev. 5:68-72.

Waghorn, T.S., D.M. Leathwick, L.Y. Chen, R.A.J. Gray, and R.A. Skipp. 2002. Influence of nematophagous fungi, earthworms and dung burial on development of the free-living stages of *Ostertagia (Teladorsagia) circumcincta* in New Zealand. Vet. Parasitol. 104:119-129.

Webster, J.E., J.W. Hogan, and W.C. Elder. 1965. Effect of rate of ammonium nitrate fertilization and time of cutting upon selected chemical components and in the in vitro rumen digestion of bermudagrass forage. Agron J. 57:323-325.

Wedin, D.A. and M.P. Russelle. 2007. Nutrient Cycling in Forage Production Systems. p. 137-148. *In* R.F. Barnes et al. (ed.) Forages: The Science of Grassland Agriculture. vol. 2. 6th ed. Ames, IA: Blackwell Publishing Professional.

West, C.P. and C.J. Nelson. 2003. Naturalized Grassland Ecosystems and Their Management. p. 315-337. *In* R.F. Barnes et al. (ed.) Forages: An Introduction to Grassland Agriculture. vol. 1. 6th ed. Ames, IA: Blackwell Publishing Professional.

White, S.L., R.E. Sheffield, S.P. Washburn, L.D. King, and J.T. Green, Jr. 2001. Spatial and time distribution of dairy cattle excreta in an intensive pasture system. 30:2180-2187.

Whitehead, D.C. 2000. Nutrient Elements in Grassland: Soil-Plant-Animal Relationships. CABI Publishing, New York.

Yamada, D., O. Imura, K. Shi, and T. Shibuya. 2007. Effect of tunneler dung beetles on cattle dung decomposition, soil nutrients and herbage growth. Japanese Soc. Grassland Sci. 53:121-129.

Yokoyama, K., H. Kai, T. Koga, and T. Aibe. 1991a. Nitrogen mineralization and microbial populations in cow dung, dung balls and underlying soil affected by Paracoprid dung beetles. Soil Bio. Biochem. 23(7):649-653.

Yokoyama, K., H. Kai, and H. Tsuchiyama. 1991b. Paracoprid dung beetles and gaseous loss of nitrogen from cow dung. Soil Biol. Biochem. 23(7):643-647.

Yokoyama, K., H. Kai, T. Koga, and S. Kawaguchi. 1991c. Effect of dung beetle, *Onthophagus lenzii* H. on nitrogen transformation in cow dung and dung balls. Soil Sci. Plant Nutr. 37(2):341-345.

CHAPTER III

A Survey of Dung Beetle Abundance and Diversity in Alpaca Pastures

ABSTRACT

Dung baited pitfall traps were used to conduct a survey of dung beetles in alpaca pastures located at Virginia State University from May to September in 2010 and 2011. Beetles were collected weekly in Petersburg, VA and identified to species. Of the 3,136 beetles collected, 11 species were represented: *Onthophagus taurus* Schreber, *O. pennsylvanicus* Harold, *O. hecate hecate* Panzer, *Copris minutus* Drury, *Phanaeus vindex* MacLeay, *Dichotomius carolinus* Linnaeus, *Sphaeridium scarabaeoides* Linnaeus, *Aphodius erraticus* Linnaeus, *A. fimetarius* Linnaeus, *A. (Nialaphodius) nigrita* Fabricius, *and A. (Labarrus) lividus* Olivier. The most common species found in both years was *O. taurus,* which accounted for 43% and 59% of the populations in 2010 and 2011, respectively. Paracoprid tunneler beetles dominated the collection in both years. The species abundance and diversity fluctuated throughout the summer, likely related to weather patterns.

INTRODUCTION

There are no recent dung beetle surveys in Virginia. Blume (1985) documents many dung beetle species as being present in Virginia, but the state lacks a thorough collection and checklist of these beneficial insects. Recent collections in North Carolina (Bertone, 2004; Lastro, 2006) and South Carolina (Harpootlian, 2001) have been extensive and have covered many regions and diverse zones. The North Carolina collections have been carried out in cattle pastures. The presence and abundance of dung beetle species in grazing systems for alpacas and other camelids is unknown.

Dung beetles are categorized into three distinct niches based on their nesting behavior by Halffter and Edmonds (1982). Endocoprid beetles lay their eggs and nest in the dung or just at the soil-dung interface. Paracoprid beetles burrow down into the soil and excavate nesting chambers underneath the dung source. The telecoprid types also form brood balls for their larvae to consume. They differ from the paracoprid beetles in that a ball of dung is rolled away from the initial source and shallowly buried in the soil with a single egg laid on it.

A few dung beetle species are species specific to a dung resource, but the majority of dung beetles are opportunistic feeders of dung. Resource selection and preference of dung type often varies by the needs of dung beetle species. For example, beetles that lay their eggs within the dung will not lay them in wet portions, but in the crust if the dung is overly wet. Gittings and Giller (1998) outline ‘findability’, physical suitability, and nutritional quality as three factors that influence the colonization of dung resources. All of these are greatly affected by the stage of dung decomposition and desiccation.

Olfactometer bioassays indicate dung beetles are attracted to dung volatiles, though the specific compounds have not yet been studied (Dormont et al., 2007). Physical factors of dung attraction were studied by Al-Houty and Al-Musalam (1997) noting a preference for moist horse dung over that of dryer sheep and camel dung by *Scarabaeus cristatus* Fab in Kuwait. When comparing cow, horse and sheep dung of the same size, Finn and Giller (2002) found a higher abundance of beetles in sheep dung than the other available dung resources. Dung resource abundance and grazing intensity have also been shown to be factors in the composition of dung beetle communities in semi-arid regions of Spain (Lobo et al., 2006).

As might be expected, climate plays a key role in composition of dung beetle assemblages (Errouissi et al., 2004). This study supports conclusions that dung size and origin are important factors impacting dung beetle communities. Because alpaca dung quality factors such as moisture content, consistency and N content vary from that of cattle dung, preference and resource selection may differ. Therefore, it is important to quantify and describe the abundance and community composition of dung beetles found in alpaca pastures in the mid-Atlantic region of the U.S.

MATERIALS AND METHODS

Collection

Dung baited pitfall traps (Fig. 3-1) were used to lure dung beetles for this study as described by Bertone (2004). Alpaca dung was collected fresh and homogenized by hand mixing weekly from May through August in two consecutive years to bait pitfall traps. The site of dung collection and beetle trapping was the alpaca unit of Virginia State University's (VSU) Randolph Farm, located outside of Petersburg, VA. Soil texture in the collection area ranged from fine sandy loam to loam. Slopes within the pasture areas ranged from 0 to 12%. Ground cover in the pastures consisted mostly of bermudagrass (*Cynodon dactylon* L.) and tall fescue (*Festuca arundinacea* Schreber). A total of 8 traps were used in 2010 and up to 16 in 2011 and were placed along the fence line of the alpaca paddocks. A greater number of traps were used in the second year to ensure collection of sufficient numbers of dung beetles for use in a greenhouse study. Number of traps also varied by date in 2011 due to damage, so relative abundance is used to present the results. Traps were baited midday and remained in the field for around 24 hours to attract both day and night flying species. All beetles for each collection date found in the traps were placed in plastic bags and frozen before being identified to species and counted.

Diversity and Relative Abundance

Shannon's Diversity Index was used as an indicator of dung beetle diversity for each week of collection. This was calculated using the following formula:

$$H' = -\sum_{i=1}^{S}(p_i \ln p_i)$$

H’ = Diversity index

S = Number of species (species richness)

p_i = Relative abundance (n_i / N) of species i

n_i = Abundance of species i

N = Total number of individuals collected

The formula used for relative abundance (p_i) is included in the equation for the diversity index. When appropriate, the abundance of beetles in 2011 has been converted to beetles per 8 traps to make the numbers comparable to 2010 where 8 traps were consistently used every week. The Renkonen index was used to calculate the percent similarity in the dung community between years. The formula for this is:

$$P = \sum \min(p_{1i}, p_{2i})$$

P = Percentage similarity between samples 1 and 2

p_{1i} = Percentage of species i in 2010 community

p_{2i} = Percentage of species i in 2011 community

The Renkonen index is commonly used and is not greatly affected by the sample size or species diversity (Krebs, 1989). Correlations of diversity index with weather factors were analyzed using JMP (SAS Institute, Cary, NC).

RESULTS AND DISCUSSION

Species Collected

Eleven species of dung beetles were collected from late May through late August in 2010 and 2011 (Table 3-1). The species collected were *Onthophagus taurus* Schreber, *O. pennsylvanicus* Harold, *O. hecate hecate* Panzer, *Copris minutus* Drury, *Phanaeus vindex* MacLeay, *Dichotomius carolinus* Linnaeus, *Sphaeridium scarabaeoides* Linnaeus, *Aphodius erraticus* Linnaeus, *A. fimetarius* Linnaeus, *A. (Nialaphodius) nigrita* Fabricius, *and A. (Labarrus) lividus* Olivier. All of the species in this community are of the Scarabaeidae family with the exception of *S. scarabaeoides*, which represents the Hydrophilidae family. Previous studies have not included the Hydrophilidae family, as Scarabaeidae is considered to contain the "true" dung beetles. Recent North Carolina dung beetle collections (Bertone, 2004; Lastro, 2006) have included the Geotrupidae family, but no species of that family were collected in this study. The species in the present collection have also been collected in North Carolina (Bertone 2004, Lastro 2006) or in South Carolina (Harpootlian, 2001).

Of the species collected, *O. pennsylvanicus, O. h. hecate, C. minutus, D. carolinus, S. scarabaeoides*, and *P. vindex* are native while the others are exotic and have origins in Europe, Africa, or Asia (Table 3-1). Native species represented 51% of the population in 2010, and 27% in 2011. This information reveals that non-native and native dung beetle species are interacting and sharing dung resources in alpaca pastures. Because both non-native and native beetles were abundant, we can conclude that the activity of the non-native species is not detrimental to the reproduction and success of the native species found in this study. Therefore, these non-native dung beetles are exotic, but do not appear to be invasive.

Endocoprid species collected were *S. scarabaeoides, A. erraticus, A. fimetarius, A. nigrita, and A. lividus*. The remaining species were all of the paracoprid nesting guild, including *O. taurus, O. pennsylvanicus, O. h. hecate, C. minutus, P. vindex, and D. carolinus* (Table 3-1). All native species collected were paracoprid beetles. The paracoprid species were generally larger beetles compared to the endocoprid. No telecoprid beetles were collected, and have only been minor species in recent collections in North Carolina (Bertone, 2004; Lastro, 2006). Paracoprid beetles were dominant in both years, representing 94% of the population in 2010 and 86% in 2011. The tunneling behavior of paracoprid dung beetles results in improvements in soil structure (Mittal, 1993) and soil nutrient levels (Bertone, 2006), which can contribute to enhanced forage growth (Lastro, 2006). One of the tunneling species found in this study, *O. taurus*, can bury 36.8 g DW dung with a single mating pair (Hunt and Simmons, 2002).

Species Abundance

A total of 1,075 beetles were collected in 2010, and 2,061 beetles were collected in 2011. Species that comprise over 5% of the population are considered to be dominant (Howden and Scholtz, 1986). The most abundant species in both years was *O. taurus*, which accounted for 43% of the population in 2010 and 59% in 2011. *Onthophagus pennsylvanicus* was the second most abundant in both years with 39% and 24% of the population in 2010 and 2011, respectively. In 2010, *C. minutus* was a dominant species at 9% of the population, but was not dominant in 2011. *A. lividus* was a dominant species in both years and comprised 5% and 13% of the population in 2010 and 2011, respectively. All other species were minor (Fig. 3-2).

Dung beetle abundance fluctuated throughout the summer. The highest abundance was recorded in early to mid July in both 2010 and 2011 (Fig. 3-3). The abundance of the two most common species, *O. taurus and O. pennsylvanicus,* also peaked during this collection period. *O.*

h. hecate individuals were not present until the beginning of July in either year. They have been seen as early as March in North Carolina collections (Bertone, 2004).

Individuals of the minor species were generally collected seasonally. *Aphodius fimetarius* and *A. erraticus* individuals were only collected in mid-June in 2010 and 2011. *Sphaeridium scarabaeoides* were only collected in mid-July, and the two *A. nigrita* beetles collected in 2010 correlate with times they were collected in 2011. The seasonal abundance of all species in both years can be seen in the Appendix.

Similarity

Despite the larger number of beetles collected in 2011, one species (*A. erraticus*) collected in 2010 was not represented in 2011. However, this was a minor species in 2010 and the percent similarity or Renkonen index in the dung beetle community between the two years was 75.6%. The high percent similarity indicates that the composition of the communities and their dominance structures did not vary greatly between years.

Shannon's Diversity Index

Species diversity includes species richness and relative abundance. By including relative abundance, calculations for species diversity account for both richness and evenness of the population. Shannon's diversity index is a commonly used index, and has been used in this study. In biological systems, this index can be as low as 0, but generally never exceeds 5. The higher the index value, the greater the diversity of the community sampled (Krebs, 1989). The overall diversity index (H') in 2010 was 1.27 and 1.09 in 2011, indicating that species diversity was greater in 2010 than in 2011 during the summer.

The highest species abundance and richness on any collection date was 7 species on July 15 in 2010 and 8 species on July 8 in 2011 (Fig. 3-3). Although the abundance and richness were the greatest on these dates, the relative species abundance, or evenness, was not necessarily higher (Fig. 3-4). Interestingly, the greatest species diversity in both years was recorded within a week of each other. The maximum diversity index was 1.40 and 1.38 in the first and second years, respectively, and occurred within the first two weeks of August. Other than peaking around the same time in the season, the trends in species diversity were not similar between the two collection years. Diversity in 2010 generally increased from May through August, while no discernable trends were seen in 2011. This is not surprising based on the greater number of traps used in 2011 along with weather differences between years.

Impact of Weather on Abundance and Diversity

Total rainfall during the 2010 collection period was 9.6 cm, which was much lower than the 38.2 cm recorded in 2011. Also, daily temperatures were 2.0° C higher on average in 2010 than in 2011 [Fig. 3-5(A,B)]. Peaks in abundance tended to fall after rainfall events [Fig. 3-6(A,B)]. While the highest peak in 2011 (360 beetles per 8 traps) occurred following the highest weekly rain accumulation, a heavy rainfall the following week resulted in a relatively low abundance (62.7 beetles per 8 traps). Also, the amount of preceding rainfall did not significantly correlate with dung beetle abundance (Fig. 3-7). This suggests that there are likely other factors, such as temperature and reproductive cycles, involved in dung beetle emergence. A probable explanation is that a large cohort of adults emerged with the first heavy rainfall, leaving few pupae in the soil when the next rainfall event occurred shortly after the first. Both *O. taurus* and *O. pennsylvanicus* adults peaked in abundance after heavy rainfall, but a closer look at the environmental cues that trigger emergence peaks in these species is needed to confirm our hypothesis that emergence was solely due to rainfall.

Dung beetle species diversity was negatively correlated with preceding rainfall, but the relationship was not strong ($P = 0.03$, $r^2 = 0.22$) (Fig. 3-8). Peaks in species diversity do not appear to coincide with rainfall events [Fig. 3-9(A,B)]. While the species richness tended to be positively correlated with rainfall, the relative abundance did not exhibit high evenness with preceding rainfall.

Previous studies have reported variations in dung beetle activity due to rainfall, drought, and temperature. Lumaret et al. (1992) saw a peak in emergence after the first heavy fall rain. This response may be similar to the peaks seen in the current study where abundance was highest following a relatively high rainfall event. The 2011 data more likely reflect the expected seasonal life cycling of dung beetles since rainfall was more abundant and evenly distributed throughout the season. Higher temperatures and less rainfall with longer drought periods likely contributed to the lower overall abundance of beetles in 2010.

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

This study has demonstrated that diverse and abundant dung beetle communities occur in alpaca pastures in the mid-Atlantic region of the United States. Dung beetle communities are valuable components in healthy pasture ecosystems. Understanding their distribution, seasonal abundance, and species diversity are all key aspects in helping researchers come up with management recommendations that preserve and build strong and active dung beetle populations.

Figure 3-1. Example of a dung baited pitfall trap used for collecting dung beetles.

Table 3-1. The type of dung beetle species described by both origin (native or exotic) and nesting guild (endocoprid or paracoprid)

Species	**Origin**		**Nesting Guild**	
	Native	**Exotic**	**Endocoprid**	**Paracoprid**
A. erraticus		**X**	**X**	
A. fimetarius		**X**	**X**	
A. lividus		**X**	**X**	
A. nigrita		**X**	**X**	
C. minutus	**X**			**X**
D. carolinus	**X**			**X**
O. h. hecate	**X**			**X**
O. pennsylvanicus	**X**			**X**
O. taurus		**X**		**X**
P. vindex	**X**			**X**
S. scarabaeoides		**X**	**X**	

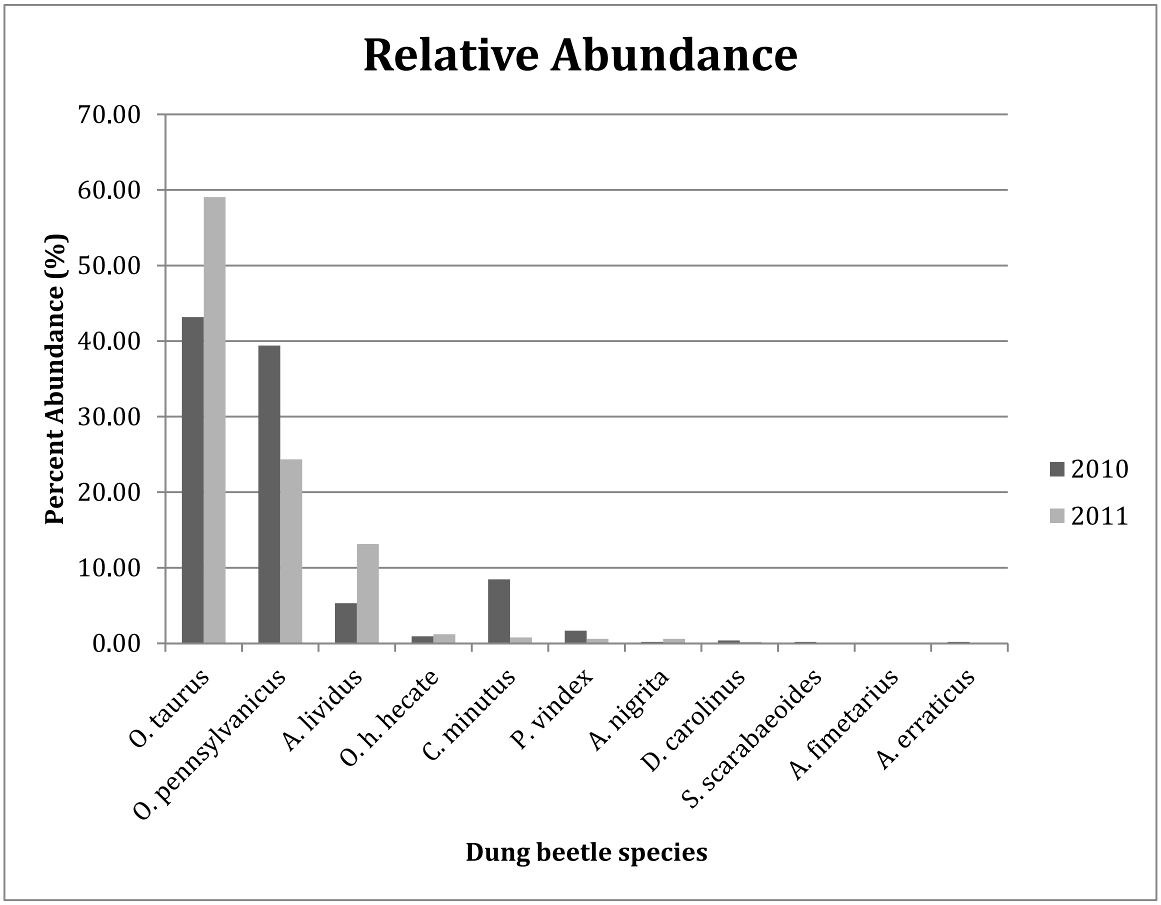


Figure 3-2. The relative abundance of each dung beetle species collected for both 2010 and 2011, represented as a percent of the total number of beetles collected each year

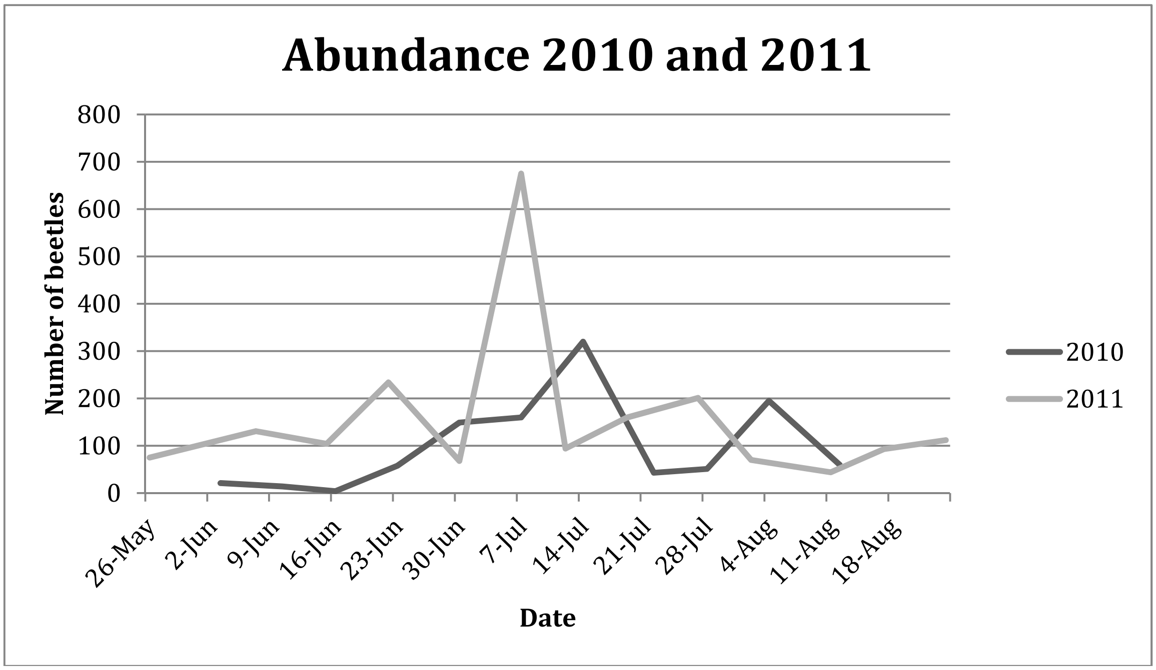


Figure 3-3. The abundance of dung beetles collected throughout each collection period

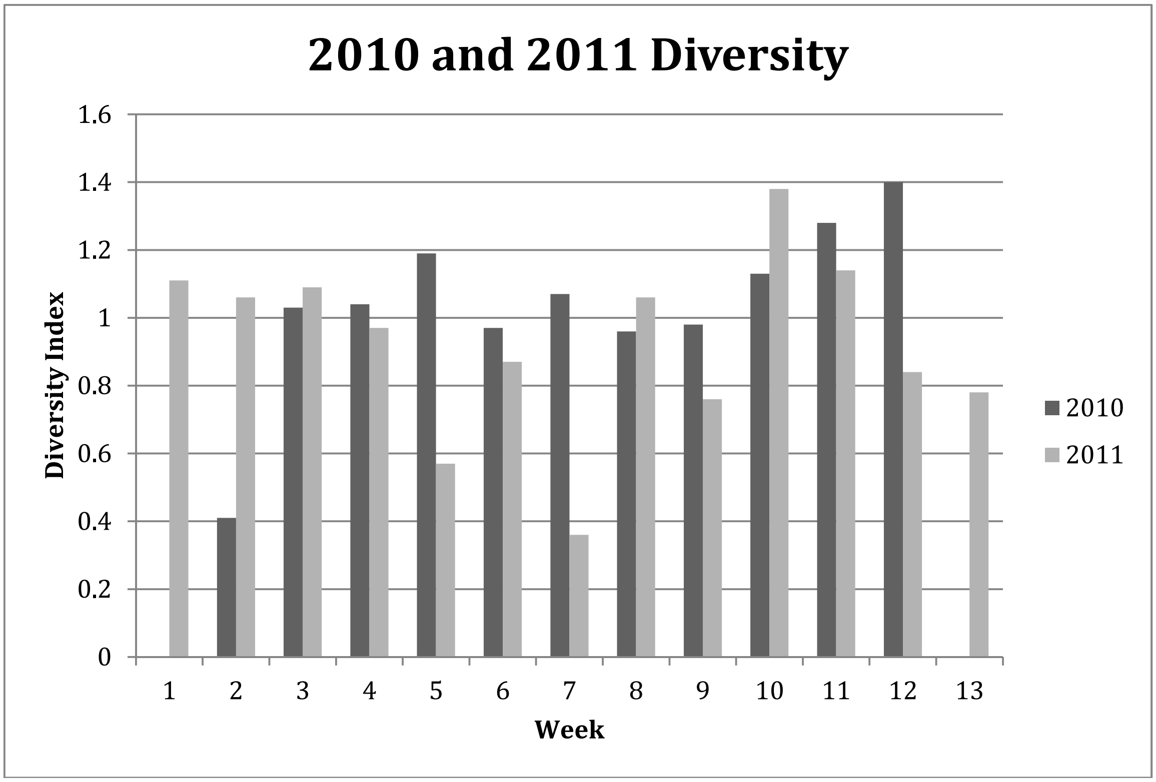


Figure 3-4. The dung beetle species diversity represented by Shannon's Diversity Index shown by collection week for both years. Week 1 starts on May 27 and week 13 ends August 25.

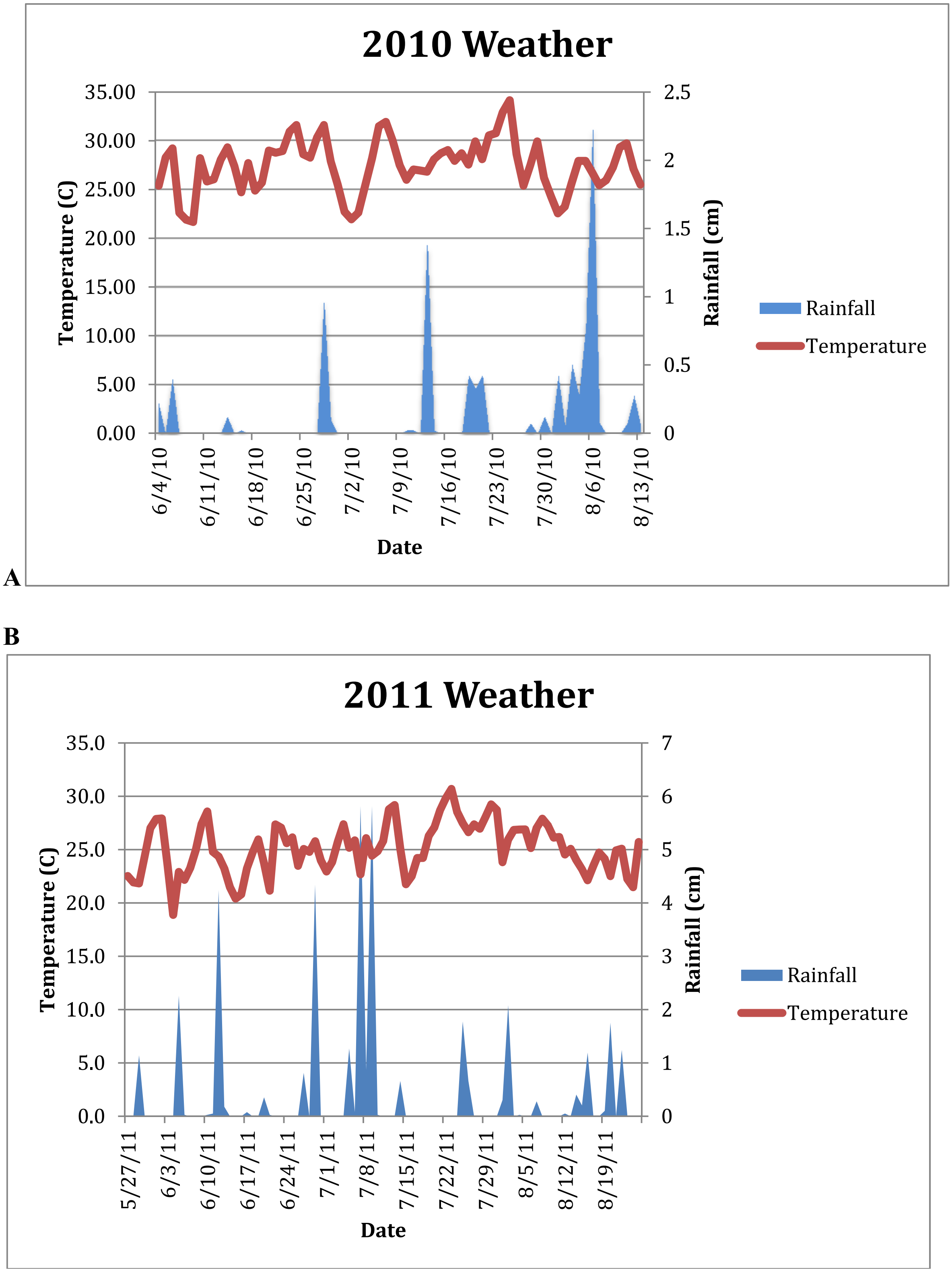


Figure 3-5(A,B). The daily rainfall and daily average temperatures are shown for the 2010 (**A**) and 2011 (**B**) collection periods

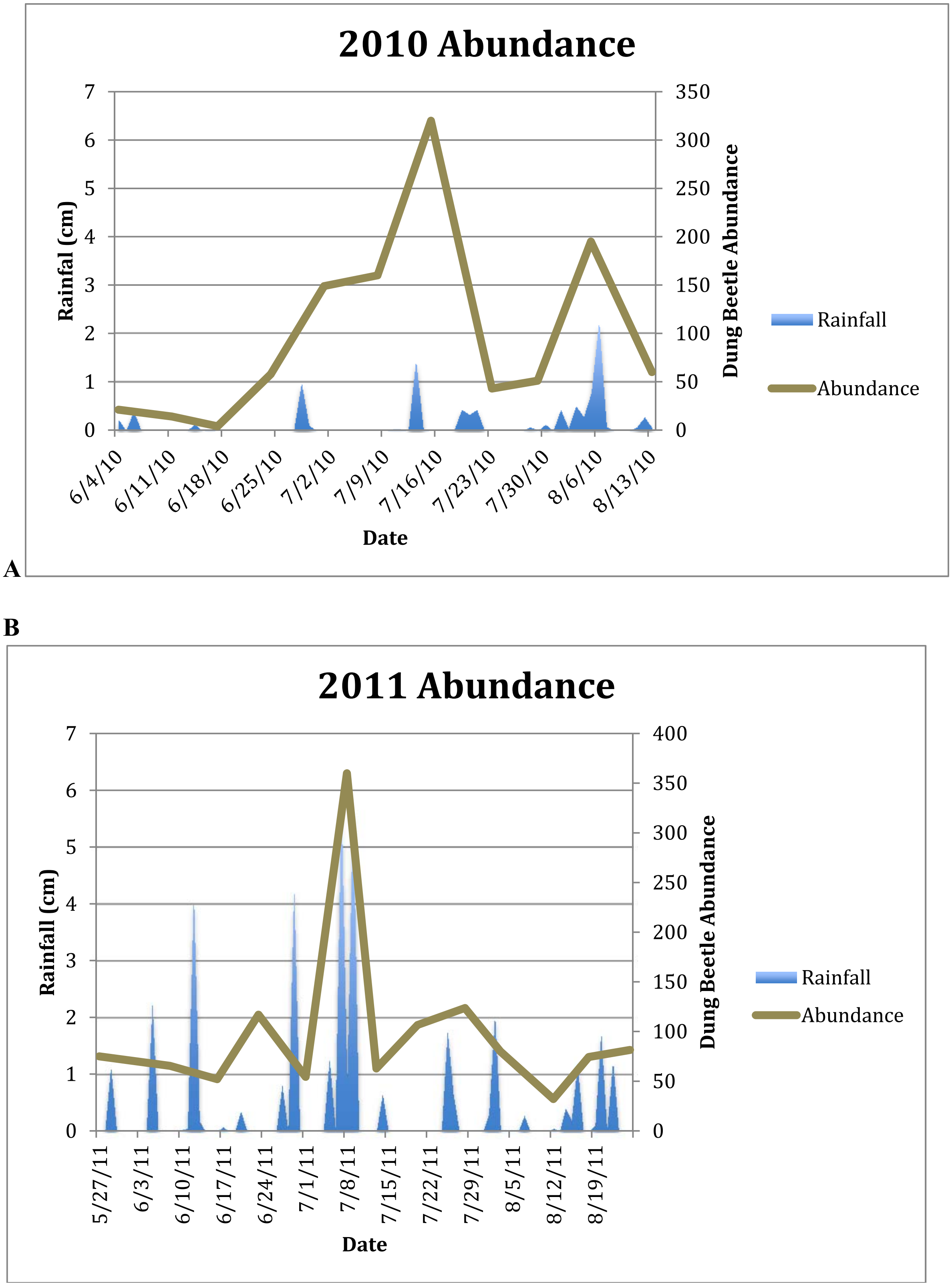


Figure 3-6(A,B). The abundance of dung beetles collected is shown along with daily rainfall throughout the 2010 (**A**) 2011 (**B**) collection periods

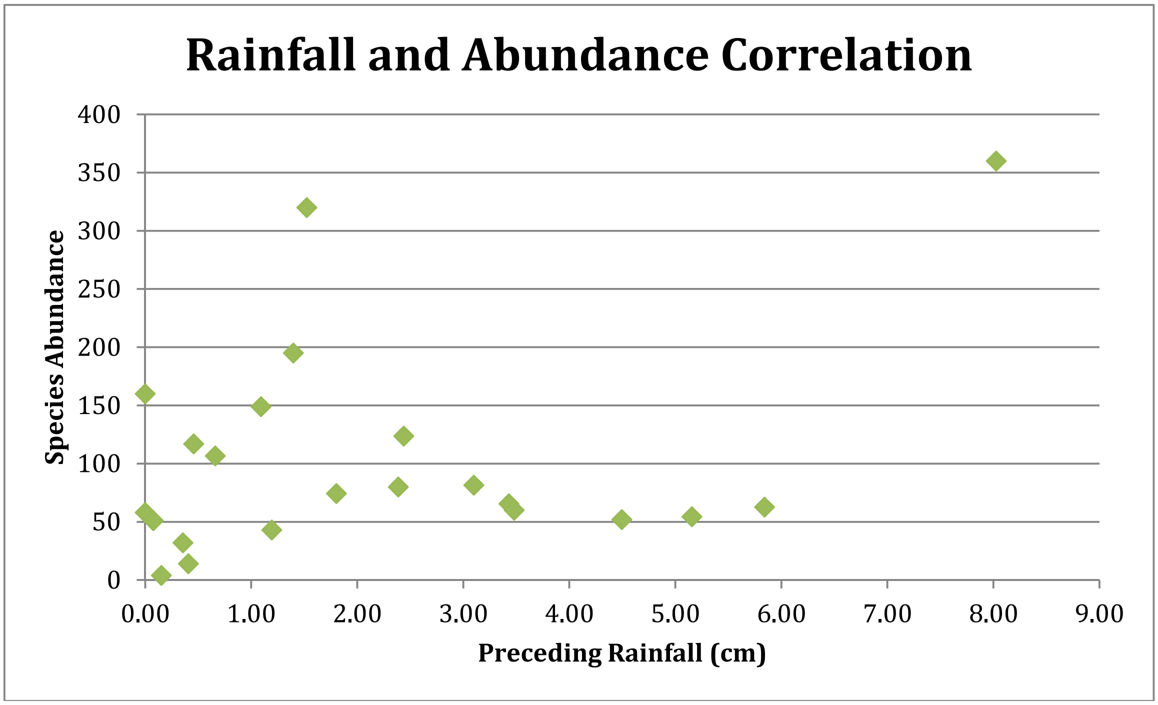


Figure 3-7. The relationship between preceding rainfall since the last collection date and the number of beetles collected on a collection date

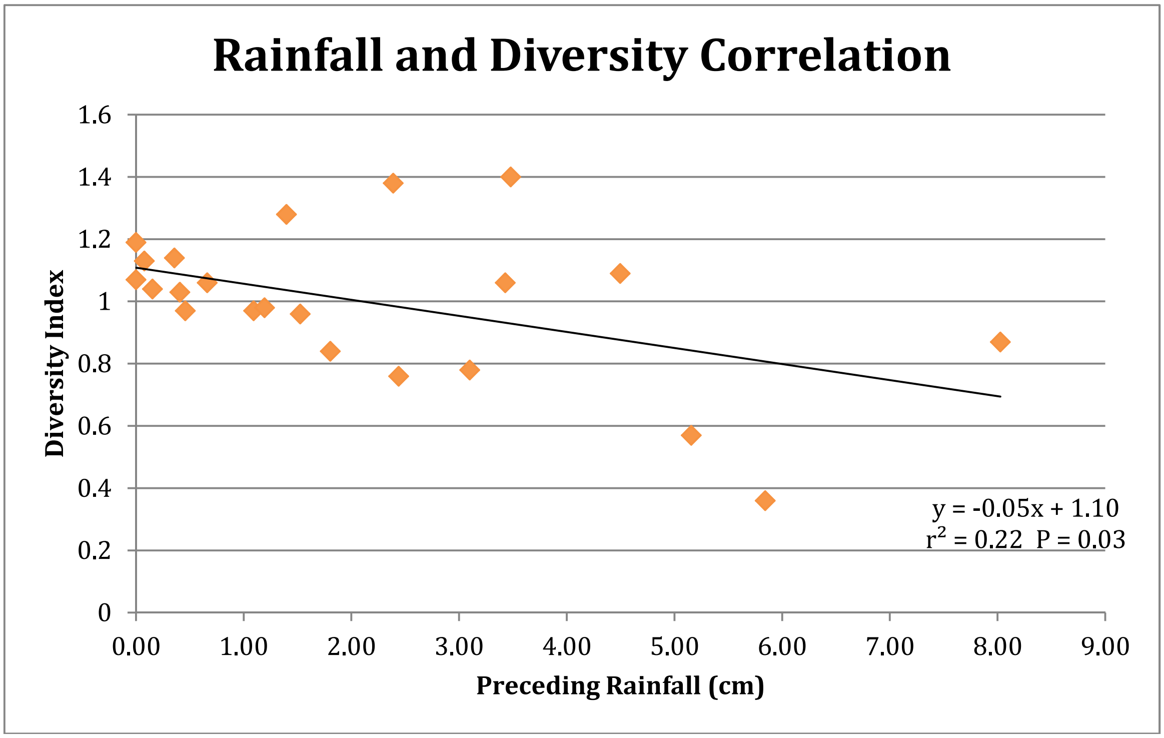


Figure 3-8. The relationship between preceding rainfall since the last collection date and the number of beetles collected on a collection date

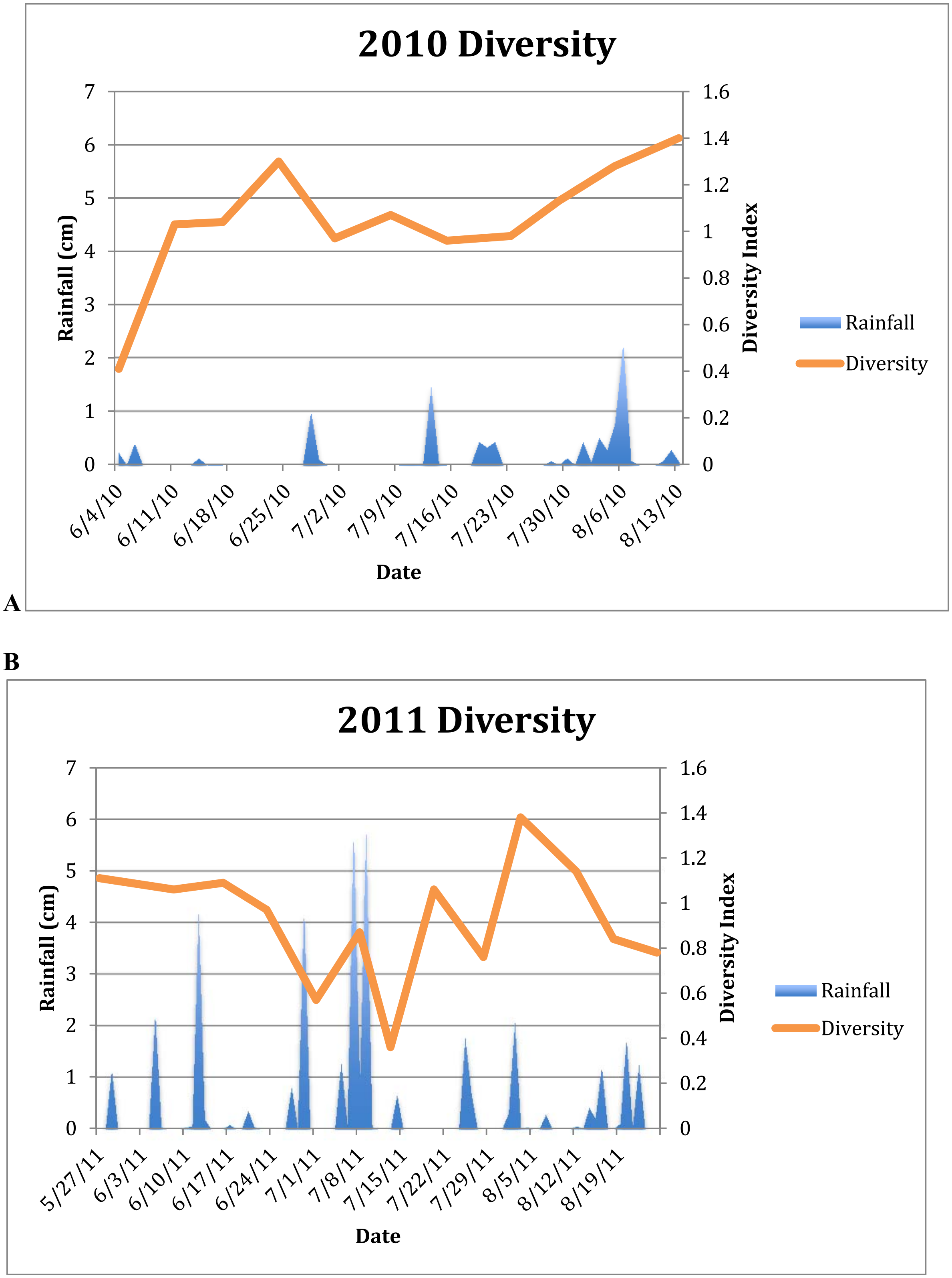


Figure 3-9(A,B). The dung beetle species diversity represented by Shannon’s Diversity Index is shown along with daily rainfall throughout the 2010 (**A**) 2011 (**B**) collection seasons

References

Al-Houty, W. and F. Al-Musalam. 1997. Dung preference of the dung beetle *Scarabeaus cristatus* Fab (Coleoptera-Scarabaeidae) from Kuwait. J. Arid Environ. 35:511-516.

Bertone, M.A. 2004. Dung beetles (Coleoptera: Scarabaeidae and Geotrupidae) of North Carolina cattle pastures and their implications for pasture improvement. PhD Dissertation. North Carolina State Univ., Raleigh, North Carolina.

Bertone, M.A., Green, J.T., Washburn, S.P., Poore, M.H., and Watson, D.W. 2006. The contribution of tunneling dung beetles to pasture soil nutrition. Forage and Grazinglands. doi: 10.1094/FG-2006-0711-02-RS.

Blume, R.R. 1985. A checklist, distributional record, and annotated bibliography of the insects associated with bovine droppings on pastures in America North of Mexico. The Southwest. Entomol. Suppl. 9:1-55.

Dormont, L., S. Rapior, D.B. McKey, and J. Lumaret. 2007. Influence of dung volatiles on the process of resource selection by coprophagous beetles. Chemoecology 17:23-30.

Errouissi, F., S. Haloti., P. Jay-Robert, A. Janati-Idrissi, and J. Lumaret. 2004. Effects of the attractiveness for dung beetles of dung pat origin and size along a climatic gradient. Commun. and Ecosys. Ecol. 33(1):45-53.

Finn, J.A. and P.S. Giller. 2002. Experimental investigations of colonization by north temperate dung beetles of different types of domestic herbivore dung. Appl. Soil Ecol. 20:1-13.

Gittings, T. and P.S. Giller. 1998. Resource quality and the colonization and succession of coprophagous dung beetles. Ecography 21:581-592.

Halffter, G. and W.D. Edmonds. 1982. The nesting behavior of dung beetles (Scarabaeinae): an ecological and evaluative approach. Instituto de Ecologia, A.C., Mexico, D.F.

Harpootlian, P.J. 2001. Scarab Beetles (Coleoptera: Scarabaeidae) of South Carolina. Bioto of South Carolina. Vol. 2. Clemson University, Clemson, SC. 157 pp.

Howden, H.F., and C.H. Scholtz. 1986. Changes in a Texas dung beetle community between 1975 and 1985 (Coleoptera: Scarabaeidae, Scarabaeinae). Coleopt. Bull. 40:313-316.

Hunt, J. and L.W. Simmons, 2002. Behavioural dynamics of biparental care in the dung beetle *Onthophagus taurus*. Anim. Behav. 64(1):65-75.

Krebs, C.J. 1989. Ecological Methodology. Harper and Row, Publishers., New York.

Lastro, E. 2006. Dung beetles (Coleoptera: Scarabaeidae and Geotrupidae) in North Carolina Pasture Ecosystems. M.S. Thesis. North Carolina State Univ., Raleigh, North Carolina.

Lobo, J.M., J. Hortal, and F.J. Cabrero-Sanudo. 2006. Regional and local influence of grazing activity on the diversity of a semi-arid dung beetle community. Divers. Distrib. 12:111-123.

Lumaret, J.P., N. Kadiri, and M. Bertrand. 1992. Changes in resources: consequences for the dynamics of dung beetle communities. J. Appl. Ecol. 29:476-483.

Mittal, I.C. 1993. Natural manuring and soil conditioning my dung beetles. Trop. Ecol. 34:150-159.

CHAPTER IV

Dung Beetles Effect on Soil Nutrient Concentrations, Forage Production and Nutritive Value

Abstract

Fertilizer prices have dramatically increased over the past decade, renewing interest in nutrient cycling in grassland ecosystems. Building and maintaining strong nutrient cycles in pastures will be key for continued profitability in ruminant livestock operations. Dung beetle activity has been shown to enhance nutrient cycling by the degradation and incorporation of dung into the soil. Previous studies have focused on cattle, and other livestock groups have received relatively little attention. The objective of this study was to evaluate the impact of dung beetle activity on soil nutrient concentrations and the growth of a common summer annual grass using alpaca dung. A greenhouse study was conducted with treatments consisting of a control (no dung, no beetles), dung only, dung with five pairs of *O. taurus*, and dung that was allowed to be colonized in an alpaca pasture. Treatment had no significant effect on soil nutrient concentrations and little effect on nutritive value. The addition of *O. taurus* and the field colonization both significantly increased total yield over the no dung control by 10% and 14%, respectively. However, it is important to remember that dung beetles are only one component of complex grassland ecosystems, and that it is important to consider all parts of the system when making management decisions.

Introduction

Grazing animals excrete 75-85% of the forage they consume, only utilizing approximately 15-25% of the N, 20-26% of the P, and 15% of the K they consume (Bellows, 2001). Where dung-decomposing organisms such as dung beetles are absent or exist in low populations, dung accumulates in pastures (Fincher, 1981). Ecological contributions to the pasture ecosystem by dung beetles have been studied from numerous angles including pest and parasite control (Bornemissza, 1970; Bryan, 1973; Bryan, 1976; Waghorn et al., 2002; Chirico et al., 2003), nutrient cycling (Lindquist, 1933; Harris et al., 1980; Gittings et al., 1994; Bertone et al., 2006), and forage growth (Bornemissza and Williams, 1970; Fincher et al., 1981; Bang et al., 2005; Yamada et al., 2007). These studies have primarily focused on the dung of cattle. Other livestock classes have received relatively little attention.

The U.S. alpaca population has grown by 81% since 2000 (Alpaca Registry, Inc., 2011). The focus of alpaca production has been on breeding stock, but the fiber market is viable with prices ranging from $70 to $110 per kg fiber. While the alpaca industry continues to grow, very little research has been done to address management of improved pastures for alpacas. Soil nutrient accumulation in communal dunging areas is an important issue in alpaca pastures. McGregor and Brown (2010) found soil nutrient levels in alpaca latrine sites to be 3.8 times higher in nitrate-N, 3 times higher in phosphorus, and 3.2 times higher in potassium than in control sites. Building and maintaining strong nutrient cycles in any improved grazing system is key to profitable livestock production. This study evaluates the effect of dung beetles on soil nutrients and the growth and nutritive value of a common summer annual grass using alpaca dung.

Soil Preparation

An Appling sandy loam (fine, kaolinitic, thermic Typic Kanhapludults) field soil collected at the Virginia Tech Southern Piedmont Agricultural Research and Extension Center (SPAREC) in Blackstone, VA was used in this study. The soil was sieved to remove roots and debris, thoroughly mixed, and tested for P, K, Ca, and Mg, using a Mehlich 1 extraction (Mehlich, 1953) and for pH using a buffer pH procedure [(soil:water = 1:1 (vol/vol)] (McLean,

1982) by the Virginia Tech Soil Testing Laboratory. Soil nutrients were tested before treatments were applied and after the final harvest of herbage. It was assumed that the mixing of the soil before filling the pots minimized soil differences between pots. For this reason, soil for pre-treatment soil testing was a composite sample from all of the pots for each trial. Pots were filled with 3.25 kg of dry soil. The dimensions of the pots had a diameter of 20 cm and were 22 cm deep, and each was lined with an autoclave bag to prevent leaching of nutrients. All pots also received a clear vinyl air tube to prevent localized anaerobic conditions and reduce preferential flow of water. Soil test results showed a pH of 6.3, which is adequate for crabgrass growth. All pots were moistened to approximately 80% field capacity before the addition of any treatments. Treatments consisted of a control (no dung, no beetles), dung only, dung with five pairs of *Onthophagus taurus*, dung that was allowed to be colonized in an alpaca pasture, along with three N rates of 45, 90, and 135 kg ha^{-1} (Table 4-1).

Dung Collection and Analysis

Alpaca dung for the trials was collected fresh from Virginia State University's (VSU) Randolph Farm, homogenized by hand mixing, and frozen until use. A subsample of the dung used in the experiment was analyzed for nutrients by Clemson University's Agricultural Services Laboratory for each trial (Table 4-2). The average mass and ground area cover of a single alpaca dunging event was determined by sampling 32 dung events. The average mass was 126.5 g and the diameter was 104.9 cm^2, and 150 g of fresh dung was used to cover an area of 112 cm^2 for the study. The surface available N estimate for the dung with 150 g fresh dung approximates a rate of 412 and 424 kg plant available N (PAN) ha^{-1} in trials 1 and 2, respectively. Because the dung remained on the soil surface for 6 days only, we do not assume that this amount of N was made available during the experiment. The amount of dung used in the experiment was chosen to mimic a single fecal event, not to achieve a fertilizer rate.

Dung Beetle Treatments

The dung beetle species used in the trials was selected because it was the most abundant species collected in Chapter III in 2010. *O. taurus* exhibit tunneling brooding behavior, burying dung resources in the soil as food for their developing larvae. Beetles for the *O. taurus* treatment were collected from baited pitfall traps in the alpaca pasture and were placed in pots with 150 g of fresh alpaca dung (Table 4-1) and covered with mosquito netting on the day that the field colonization treatments were exposed to dung beetles. The field colonization treatment pots also received 150 g of alpaca dung (Table 4-1), and were placed in the ground so that the top of the pot was at the soil surface to mimic the placement of a natural dunging event (Fig. 4-1A). Pots were placed near the primary communal dunging area at VSU and left for 24 hours to allow both night and day flying dung beetles to colonize the dung. Once removed from the field, pots were also covered with mosquito netting to prevent the beetles from escaping and transported to SPAREC where they were placed in a greenhouse with the other pots. Collections from baited traps were used to estimate the species diversity and relative abundance of the dung beetle community that colonized the pots. Netting as well as any dung remaining on the soil surface was removed from all treatment pots containing dung after 6 days. Remaining dung was analyzed for nutrients at Clemson University.

Planting and Fertilizer Application

After the netting and dung were removed from pots, ‘Quick N Big’ crabgrass [*Digitaria ciliaris* (Retz.) Koel] was evenly seeded into all pots at a rate of 25 seeds per pot using a seeding template. Seeding dates for trials 1 and 2 were August 3 and August 8, respectively. Seeding depth was 0.6 cm and seedlings were thinned to 14 plants per pot after germination. Potassium (K) and phosphorus (P) were adjusted based on soil test recommendations (Donohue and Heckendorn, 1994) by adding lab grade KCl and $Ca(H_2PO_4)_2$ as a 150 ml solution in deionized water pot^{-1} after germination (Table 4-1). All pots received P and K to ensure that these nutrients were not limiting to plant growth. Soil test recommendations for P and K were 20 mg P_2O_5 kg^{-1} and 40 mg K_2O kg^{-1}. Four times the recommended P_2O_5 was added to account for significant P fixation in the pots. Nitrogen treatment levels were selected to create a response for grass yield. The fertilizer source was laboratory grade $Ca(NO_3)_2$ and was applied as a 180 ml solution in deionized water pot^{-1} after seedling emergence and thinning (Table 4-1). Pots were kept at approximately 80% field capacity by weight using deionized water to ensure that moisture was not a growth-limiting factor.

Data Collection

When crabgrass growth consistently reached the early head stage, the pots were harvested by hand cutting to 10 cm residual height. Two harvests were taken for each trial with the first harvest occurring September 5 and September 9 for trials 1 and 2, respectively. The second harvest occurred approximately 3 to 4 weeks later on September 27 and September 30 for trials 1 and 2, respectively. Harvested shoots were weighed, dried, reweighed and ground for lab analysis. Total N was determined using a modified Dumas method (Elementar Americas, Mt. Laurel, NJ), and crude protein (CP) calculated by multiplying the total nitrogen content by 6.25. Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were determined using the ANKOM filter bag method (ANKOM Technology, Macedon, NY). After the second harvest, soil samples were collected from each pot and analyzed individually. The lower 10 cm of stem growth was harvested along with root mass, which was washed free of soil. Fresh and dry weights were taken for both the stem and root mass. Soil samples were collected from each pot after the second harvest and analyzed for nutrients. The soil was analyzed for P, K, Ca, Mg, organic matter (OM), cation exchange capacity (CEC), pH, and base saturation (BS). Total soil nitrogen and carbon in the soil was also determined using a modified Dumas method (Elementer Americas, Mt. Laurel, NJ).

Statistical Analysis

The experimental design was a randomized complete block with seven treatments and four replications. The study was repeated twice. Data from dung and soil nutrients, forage yield and nutritive value were analyzed using the general linear model procedure from SAS (SAS Institute, Cary, NC), and Fisher's Protected Least Significant Difference (LSD) ($\alpha = 0.05$) was used. Any significant trial by treatment interactions are presented by trial. A response curve was created using the N treatments (0, 45, 90, and 135 kg ha^{-1}) to measure the growth response of crabgrass to N rate. Using Sigma Plot 11.0 (Systat, Point Richmond, CA) the response curve was used to estimate PAN provided by dung and dung beetle treatments by solving for the y-value in the curve equation, using the dry matter yield as the x-value.

Observed Dung Beetle Activity

After 24 hours of dung beetle activity in the field treatment pots, dung pats were nearly completely shredded and no longer resembled their original form. Less visible activity was seen in *O. taurus* pots, but several tunnels and some distribution of the dung was common [Fig.4-1(A-D).] It is unknown how much dung the beetles in this study buried, but Hunt and Simmons (2002) recorded 36.8 g DW dung buried by a single pair of *O. taurus* beetles. When the dung was removed from the soil surface, tunnel openings could be seen in both dung beetle treatments. A variety of sizes of tunnels were visible with field colonized pots, with a large number of small tunnels likely created by *O. pennsylvanicus* or by shallow burrowing by *Aphodius* species. Complete removal of dung from field colonized pots was difficult as it was highly shredded and somewhat incorporated into the soil surface. Yamada et al. (2007) saw similar increased rates of decomposition by increasing dung beetle density in a field study.

Dung beetles collected in traps during the time period when the field colonization treatment pots were in the field were identified to species for both trials. In the first trial, dung beetle species collected were *O. taurus, O. pennsylvanicus, C. minutus, A. lividus, and A. nigrita*. The same species were collected the following week for trial 2 with the addition of *O. hecate*. The abundance of beetles recorded in the field during the first trial was lower than that during the second trial, with 80 beetles collected in the first trial and 124 collected in the second. The species diversity index values were calculated in Chapter III and were 0.76 in the first trial and 1.38 in the second, indicating greater diversity in trial 2.

Treatment Effects on Soil Qualities

Trial by treatment interactions were not significant, so data are presented averaged over trials. No differences were seen between treatments for soil nutrients or for CEC, BS, or OM (Table 4-3). There were also no differences between treatments for organic-N, ammonium-N, P_2O_5, or K_2O in the alpaca dung after six days of exposure (Table 4-2). Previous greenhouse studies in North Carolina that have tested dung beetle benefits to soil nutrients have included two dung deposition periods of 250 g over time, rather than the single event simulated in the present study (Bertone, 2004; Lastro, 2006). Bertone (2004) saw increased K, Mg, Ca, Mn, and Zn levels over dung alone with *Onthophagus gazella* Fabricius beetles in sandy loam soil, but *O. taurus* beetles significantly increased only K and Ca levels. Soil P and K levels were increased with 5 pairs of *O. taurus* over dung only and pre-treatment levels in Lastro (2006). Bornemissza and Williams (1970) used a single deposition of 250 g dung in a greenhouse study that resulted in increased yield and N, P, and sulfur uptake with dung beetle activity. The additional amount of dung and dung beetle activity may have contributed to the significant increase in soil nutrients in those studies. Nutrients levels were also monitored in soils by Yamada et al. (2007), who noted an initial spike in N, P, and K with dung beetle activity that returned to original levels within a few weeks. It is possible that the same trend occurred with nutrients in the present study and that nutrient levels dropped off by the final soil sampling.

Dung consistency, moisture content, and microbial population differences between the alpaca dung used in this study and the cattle dung used in all previous studies may also have been a factor in the lack of significant differences in soil qualities. More research is required to determine the effect of dung type on soil nutrient levels following dung beetle activity.

Treatment Effects on Dry Matter Yield

First Harvest

In the first harvest, dung beetle activity increased crabgrass yield over the dung only and control treatments. When N rate treatments were excluded from statistical analysis, yield in pots with field colonization of dung beetles was significantly higher than the dung only and the no dung control (Fig. 4-2). The *O. taurus* treatment yield was significantly higher than the control, but was not different from the dung only. Field colonization did not significantly increase the yield over *O. taurus* alone.

There was no yield response to N rate in the first harvest (Fig. 4-3), therefore we do not conclude that the N content of the dung was responsible for the higher yield in the dung and dung beetle treatments. The reason for a lack of yield response to N rate in this study is unknown. Soil P and K should not have limited yield. Soil tests were not taken following the first harvest, but no significant soil nutrient differences were seen at the final harvest. Enhancements in soil physical properties such as increased water infiltration and water holding capacity may have resulted from the addition of dung and dung beetles that made soil conditions more favorable for plant growth, although water was not limiting. Brown et al. (2010) observed higher water infiltration and greater porosity in the root zone after just 48 hours of dung beetle activity. Bang et al. (2005) also reported increased permeability in the root zone with dung beetle activity. Small amounts of shredded dung that was incorporated into the soil surface in the field colonized pots could have also contributed to enhanced seed germination and seedling development. Soil moisture conditions in the periphery of dung pats have been shown to enhance grass seedling emergence and development (Akbar et al., 1995; Gökbulak, 2009).

While no soil nutrient differences were seen in this study, dung beetle activity appears to be beneficial to seedling establishment, initial growth, and first harvest yield. These results indicate that increased dung beetle diversity and likely increased dung beetle abundance can enhance initial forage growth. Although this was not observed by Yamada et al. (2007) where increasing dung beetle density did not increase yield.

Second Harvest

Trial by treatment interaction effects occurred for the second harvest, so results are presented by trial. Yield increased with N rate in both trials (Fig. 4-4), supporting results from Teutsch et al. (2005) where yield increased with N rate in the second harvest of crabgrass. Treatment differences were not seen for dung or dung beetle treatments in either trial (Fig. 4-2). Under field conditions, Yamada et al. (2007) observed an increase in soil N from 5 mg kg^{-1} to around 18 mg kg^{-1} after dung beetle activity until day 7, followed by a decrease in soil N and a concentration of 10 mg kg^{-1} by day 56 of the experiment. The second harvest in the present experiment occurred at 60 days after dung beetles were introduced, so based on the observations of Yamada et al. (2007), it is likely that the remaining N content in the soil was low and did not result in a yield response in the second harvest.

Total Harvest

Herbage harvested to a 10 cm residual height was summed for both harvests. No trial by treatment interaction was observed, so data is averaged over trials. Overall, yield was positively correlated with increasing N rate (Fig. 4-5). This supports previous field studies with crabgrass where forage yiled increased as N rate increased (Dalrymple, 1993, Teutsch et al., 2005). Yield was also increased with increasing dung beetle diversity (Fig. 4-2 and 4-5). All treatments had significantly higher yield than the control except for 45 kg N ha^{-1}, which was only numerically higher. The yield increase over the control for the *O. taurus* and field treatments were 10% and 14%, respectively. While dung beetles numerically increased the yield over dung only, no statistically significant increases were seen with the addition of dung beetles (Fig. 4-2). All treatments containing dung yielded significantly higher than the control. This supports the results of Lastro (2006) where annual ryegrass and sudangrass yield following dung beetle activity was greater than the control. Root and stem dry weights were not statistically different between treatments (Table 4-4).

Treatment Effects on Forage Nutritive Value

NDF and ADF Concentrations

Trial by treatment interactions were significant for NDF in the first harvest, so interaction means are reported by trial for this harvest (Tables 4-5). Treatment had no effect on NDF in trial 1, but was significant in trail 2 ($P < 0.001$). In the second trial, increased N rate resulted in decreasing NDF. Also, NDF of *O. taurus*, field, dung only, and control treatments were all significantly higher than N rate treatments. In harvest 2, no interaction effects were seen and there were no significant differences between treatments for NDF (Table 4-6).

Nitrogen rates and dung beetle treatments had no effect on ADF for either harvest. Bang et al. (2005) also saw no significant differences in ADF with the addition of dung beetles. The average total digestible nutrients (TDN) for all treatments was within the recommended range for alpaca maintenance requirements (50-65% TDN) for both harvests.

Protein

Trial by treatment interaction was significant for CP in the first harvest, so results are reported by trial. In both trials, CP increased with N rate, but trends for dung and dung beetle effect varied by trial (Tables 4-5 and 4-6). No significant differences were seen in CP across treatments in the second harvest. Crude protein averages for the 135 kg N ha^{-1} in trial 1 and all treatments in trial 2 other than the dung only and *O. taurus* treatments were within the 12-16% range seen in previous studies (Dalrymple, 1993; Dalrymple 1994) for the first harvest (Table 4-5). All average CP percentages were below this range for the second harvest (Table 4-6). The only N application in this study came prior to the first harvest, and likely contributed to the adequate CP concentrations in the first harvest. Mineralizable N remaining in the soil after the first harvest was likely low, resulting in the lower CP concentrations in the second harvest.

PAN with Alpaca Dung and Dung Beetles

When rainfall is adequate, the most limiting factor to plant productivity is N. Nitrogen increases dry matter yield and leafy growth of forage plants (Noller and Rhyderd, 1974). There was no noticeable trend in the effect of N rate on yield in the first harvest (Fig. 4-3), but there was for harvest 2 (Fig. 4-4) and total harvest (Fig. 4-5). Total harvest (harvest 1 + harvest 2) yield exhibited a linear response to N rate (Fig. 4-5). The estimated PAN for dung only, *O.*

taurus, and field treatments were 76.0, 87.9, and 126.4 kg PAN ha^{-1}, respectively (Fig. 4-5). All dung treatments provided more PAN than the 45 kg N ha^{-1} treatments (Fig. 4-5). When looking at treatment effect on the remaining N, P, and K in manure after dung was removed from pots after six days, there were no significant differences between the dung only and dung beetle treatments (Table 4-2).

Summary and Management Implications

Pasture ecosystems are complex, and the soil component is often overlooked. Soils are home to a wide array of living organisms, including insects, earthworms, fungi, bacteria, algae, protozoa, and nematodes. These organisms function jointly to promote nutrient cycling and soil aggregation (Bellows, 2001). Due to the complex nature of pasture ecosystems, firm conclusions are difficult to draw from experiments, such as this one, where a single component of the functioning ecosystem has been isolated. Despite this fact, our results indicate that dung beetles have the potential to improve forage yield. We saw this primarily in the first harvest when beetles were at field population levels. This supports previous greenhouse and field studies where cattle dung was used (Bornemissza and Williams, 1970; Fincher et al., 1981; Bang et al., 2005; Lastro, 2006; Yamada et al., 2007).

The results of the current study indicate that dung beetles can enhance pasture growth, however the communal dunging behavior of alpacas may limit the positive impact of dung beetles on nutrient cycling. Communal dunging concentrates manure and its associated nutrients in relatively small areas. Even with an abundant dung beetle population and a diverse soil ecosystem, there is low efficiency in nutrient cycling without an even distribution of animal excreta. Management recommendations that may improve nutrient distribution in alpaca pastures include relocating latrine sites, co-grazing alpacas with other ruminant livestock, and increasing stocking density. These methods encourage more uniform pasture utilization, and improve the evenness of dung and urine distribution.

Table 4-1. Inputs of nutrients, dung, and dung beetles by treatment

Treatment	$Ca(NO_3)_2$	$Ca(H_2PO_4)_2$	KCl	Alpaca Dung	Dung Beetles
	---------------------mg kg^{-1}---------------------			----g pot^{-1}----	
0 kg ha^{-1}	0.0	142.0	63.3	--	--
45 kg ha^{-1}	20.0	142.0	63.3	--	--
90 kg ha^{-1}	40.0	142.0	63.3	--	--
135 kg ha^{-1}	60.0	142.0	63.3	--	--
Dung Only	--	142.0	63.3	150	--
O. taurus	--	142.0	63.3	150	5 pairs O. taurus
Field Colonization	--	142.0	63.3	150	Field levels

Table 4-2. Dung nutrient analysis results for each trial. “Fresh” refers to the analysis before treatments were applied, while the “After Exposure“ shows the average dung analysis after six days of exposure to each treatment.

Dung Status	**Organic N**	**Ammonium N**	**P_2O_5**	**K_2O**
	------------------------------------% Dry Matter------------------------------------			
Fresh				
Trial 1	2.52	0.43	2.74	1.00
Trial 2	2.43	0.31	2.71	1.26
After Exposure*				
Dung Only	2.39 a	0.63 a	1.12 a	0.69 a
O. taurus	2.14 a	0.63 a	1.04 a	0.64 a
Field	1.87 a	0.33 a	1.08 a	0.60 a

*Different letters within a column designate significant differences in dung nutrients after exposure to the treatments using Fisher’s Protected LSD ($\alpha = 0.05$)

Table 4-3. Soil test results after second harvest, averaged over trials

Treatment	**P**	**K**	**Ca**	**Mg**	**Organic Matter**	**CEC**	**pH**	**Base Saturation**
	---------------------mg kg^{-1}---------------------				----%----	meq 100 g^{-1}		----%----
Control	46.7	5.0	1268.0	36.1	3.7	6.7	6.9	99.3
Dung Only	43.9	4.9	1252.4	36.1	3.7	6.6	7.0	99.8
O. taurus	41.6	6.2	1226.3	35.1	3.6	6.5	6.9	99.4
Field	45.6	5.2	1225.3	40.3	3.8	6.5	7.0	99.6
45 kg N ha^{-1}	49.8	5.5	1280.1	37.8	3.7	6.7	7.0	99.7
90 kg N ha^{-1}	44.7	6.5	1273.5	37.7	3.7	6.7	7.0	99.5
135 kg N ha^{-1}	44.7	6.4	1311.3	40.0	3.8	6.9	7.1	99.7
Standard Error	3.5	0.6	57.4	2.2	0.2	0.3	0.1	0.2
LSD ($\alpha = 0.05$)	ns	ns	ns	ns	ns	ns	ns	ns

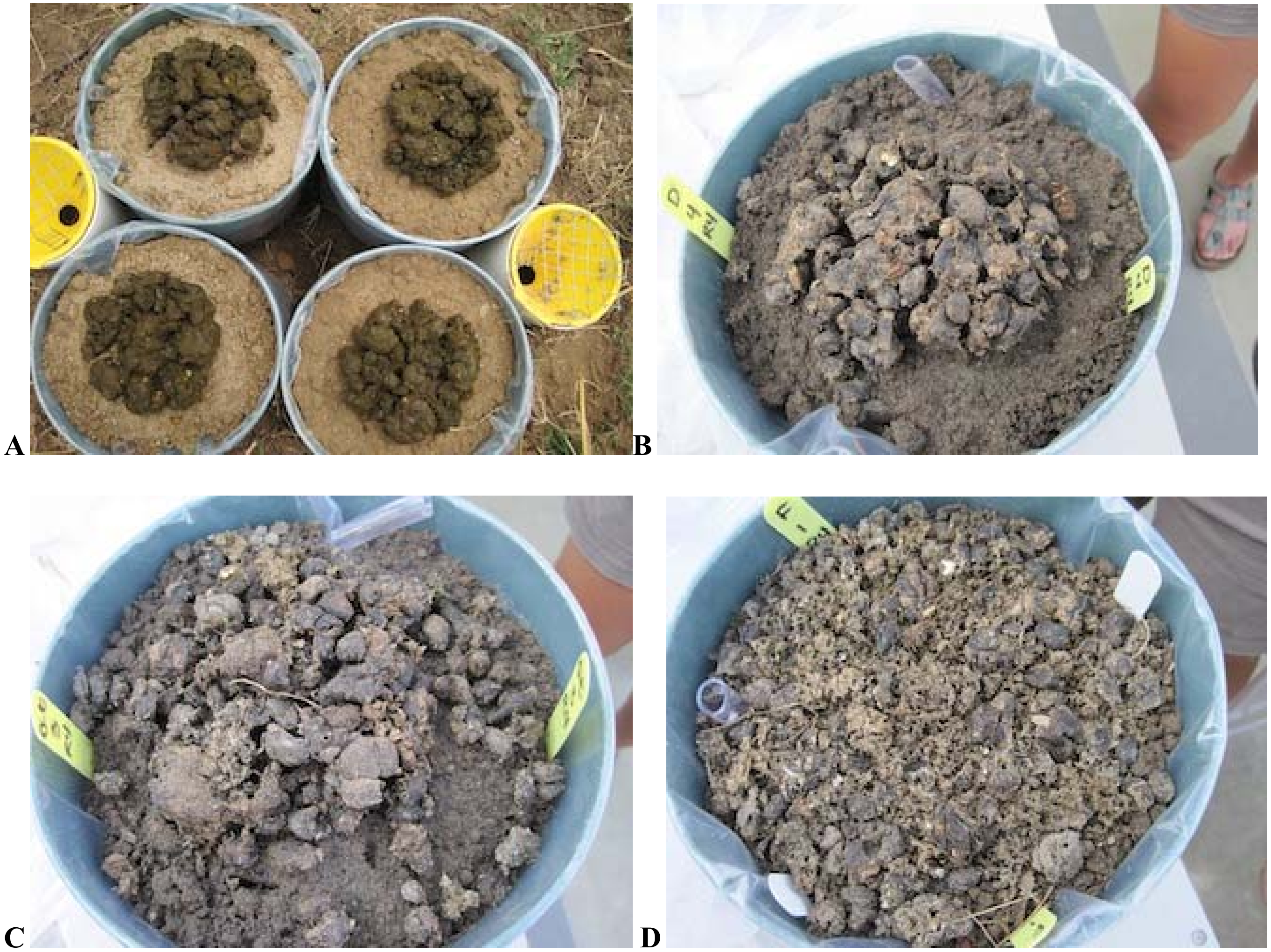


Figure 4-1. Fresh dung on field treatment pots (**A**); Dung only after 6 days (**B**); Dung after 6 days of *O. taurus* activity (**C**); Dung after 6 days of activity from field colonization of dung beetles (**D**)

Table 4-4. Root and stem mass averaged over trials

Treatment	**Root Yield**	**Stem Yield**	**Root + Stem**
	----------------g pot^{-1} Dry Matter----------------		
0 kg N ha^{-1}	8.7	3.1	11.8
45 kg N ha^{-1}	7.8	3.2	11.0
90 kg N ha^{-1}	7.5	3.3	10.8
135 kg N ha^{-1}	7.8	3.5	11.3
Dung Only	9.2	3.3	12.5
O. taurus	9.8	3.6	13.4
Field Colonization	7.6	3.7	11.3
LSD ($\alpha = 0.05$)	ns	ns	ns

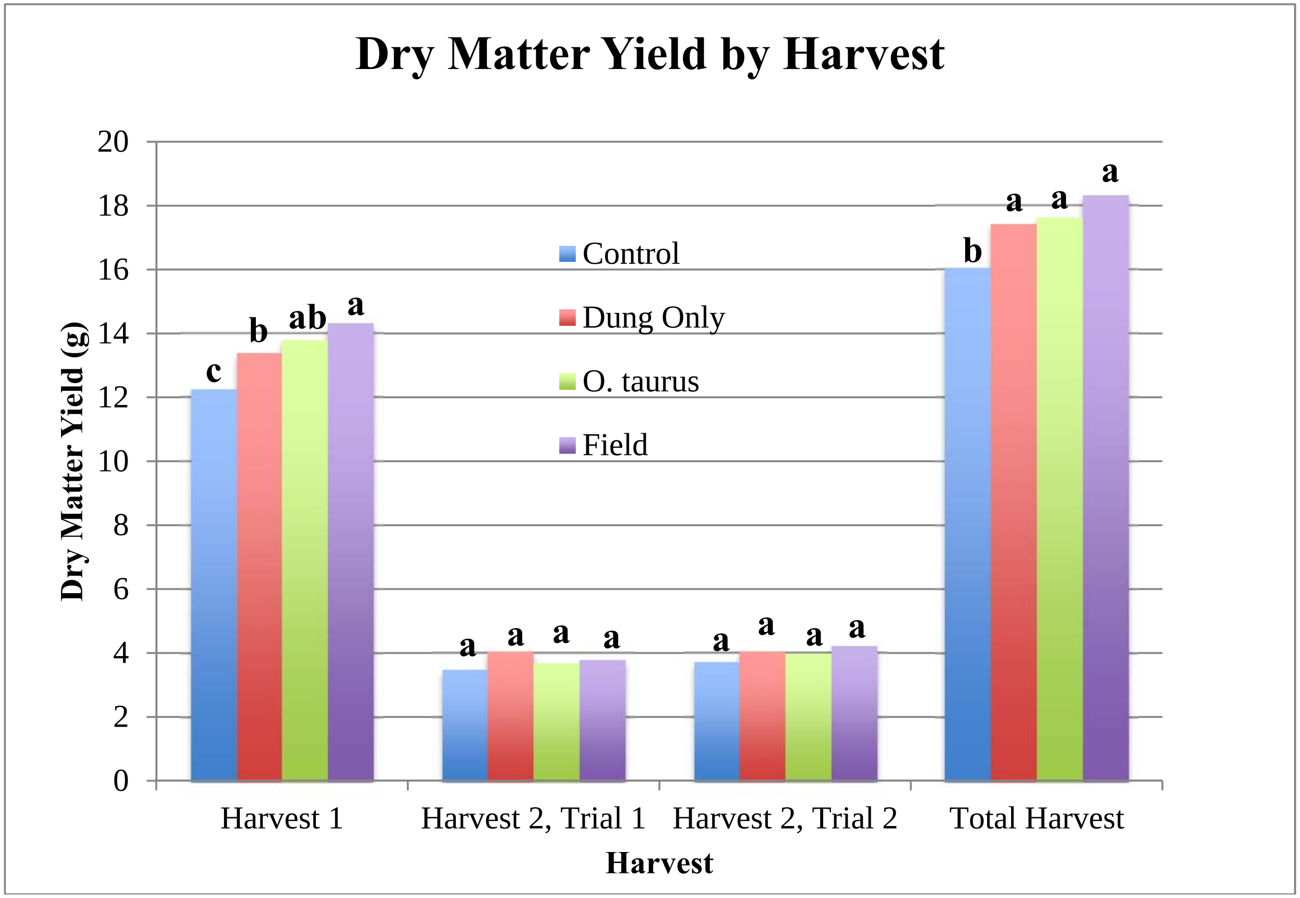


Figure 4-2. Average dry weight yield as impacted by dung beele activity for the first, second, and total harvest. Different letters within each harvest indicate significant difference using Fisher's Protected LSD ($\alpha = 0.05$).

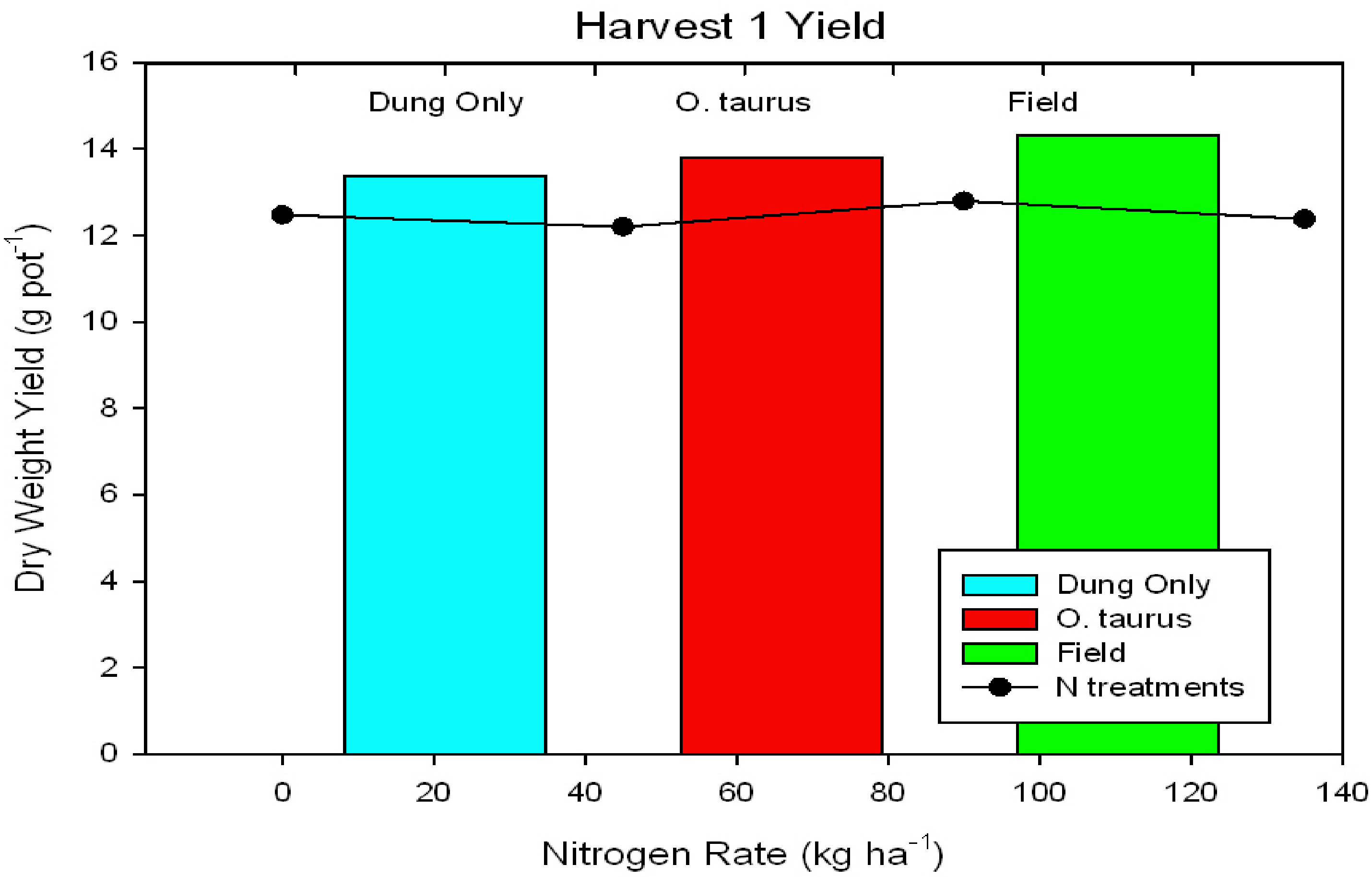


Figure 4-3. Nitrogen rate and dung beetle effects on first harvest dry weight yield, averaged over trials

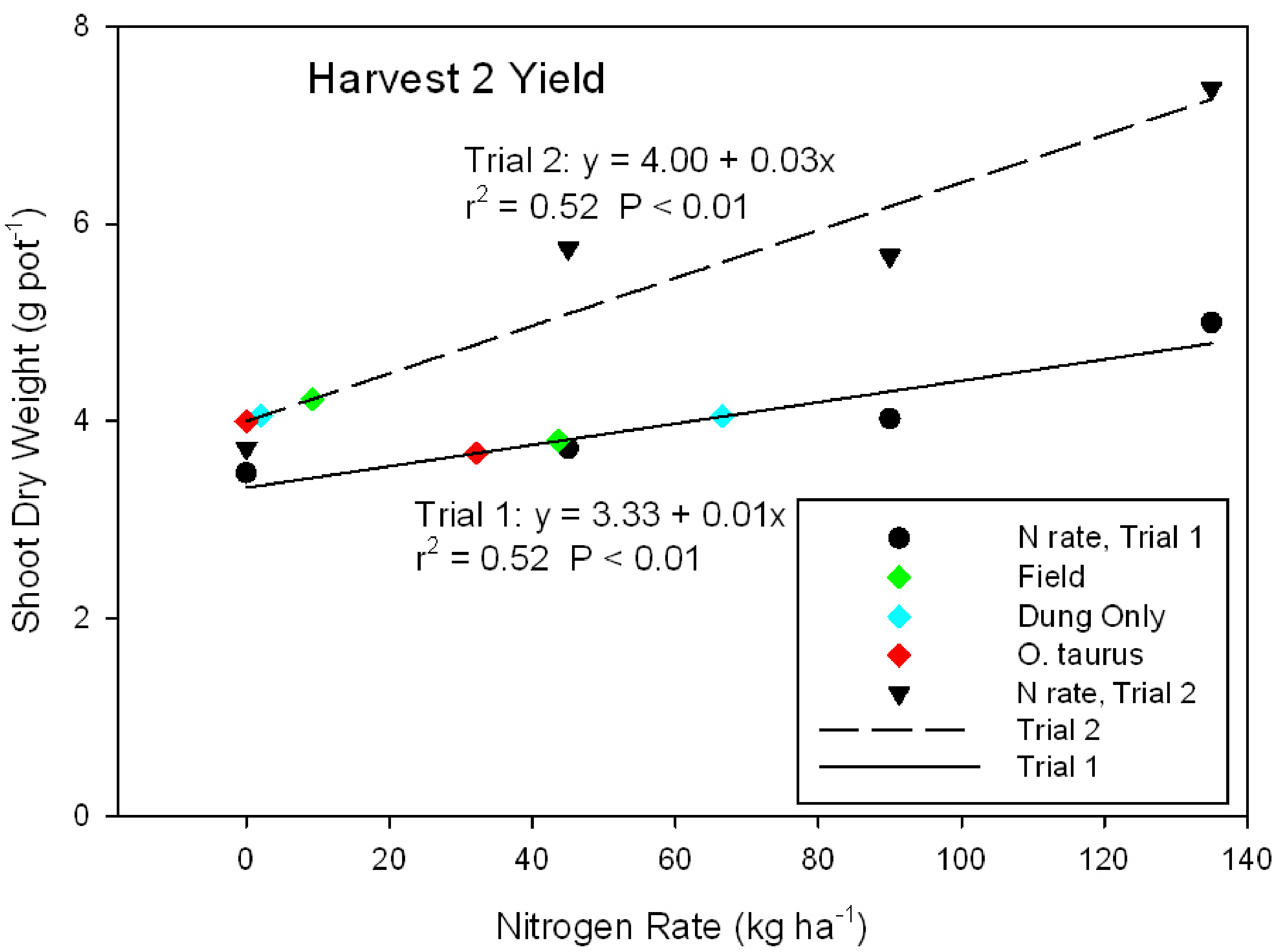


Figure 4-4. Nitrogen rate and dung beetle effects on second harvest dry weight yield for each trial

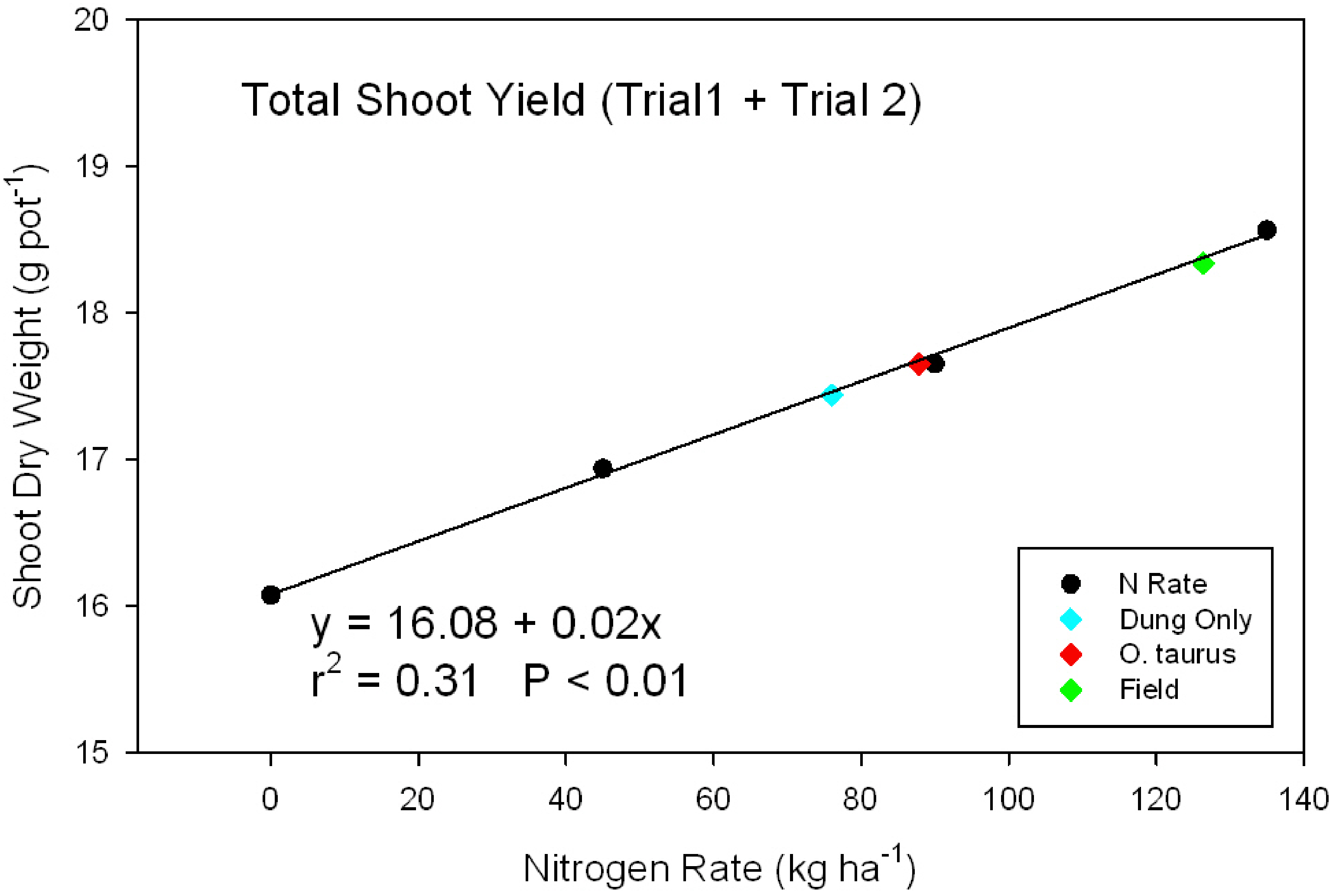


Figure 4-5. Nitrogen rate and dung beetle effects on total harvest dry weight yield, averaged over trials

Table 4-5. Harvest 1 forage nutritive quality results for neutral detergent fiber (NDF), and crude protein (CP), averaged for each trial, and acid detergent fiber (ADF) and total digestible nutrients (TDN), averaged over both trials.

	0	**45**	**90**	**135**	**Dung Only**	***O. taurus***	**Field**	**Average**
	-------------------------- kg ha^{-1}--------------------------							
Trial 1								
NDF (%)	58.5 a	59.6 a	56.8 a	56.2 a	57.7 a	58 a	57.2 a	57.7
CP (%)	8.5 d	10.1 bc	11.3 b	14.2 a	9.8 bcd	8.8 cd	10.9 b	10.5
Trial 2								
NDF (%)	58.6 a	55.3 b	54.3 bc	52.1 c	58.2 a	58.8 a	58.0 a	56.5
CP (%)	13.0 cd	15.9 bc	18.9 ab	21 a	11.5 d	11.6 d	12.8 cd	15.0
Both Trials								
ADF (%)	37.8 a	36.6 a	37.1 a	36.1 a	36.9 a	37.5 a	37.4 a	37.1
TDN (%)	58.0 a	59.4 a	58.8 a	59.9 a	59.0 a	58.4 a	58.5 a	58.9

*Different letters within a row indicate significant difference using Fisher's Protected LSD Test ($\alpha = 0.05$).

Table 4-6. Harvest 2 forage nutritive quality results for acid detergent fiber (ADF), neutral detergent fiber (NDF), crude protein (CP), and total digestible nutrients (TDN), averaged over trials.

	0	**45**	**90**	**135**	**Dung Only**	***O. taurus***	**Field**	**Average**
	----------------------------kg ha^{-1}----------------------------							
NDF (%)	59.9 a	58.7 a	58.4 a	56.9 a	59.8 a	60.2 a	60.4 a	59.2
CP (%)	6.8 a	6.9 a	7.5 a	7.6 a	6 a	6.6 a	7.1 a	6.9
ADF (%)	41.2 a	41.6 a	41 a	40.3 a	42.1 a	41.1 a	41.8 a	41.3
TDN (%)	54.3 a	53.5 a	54.6 a	55.3 a	53.3 a	54.3 a	53.5 a	54.1

* Different letters within a row indicate significant difference using Fisher's Protected LSD Test ($\alpha = 0.05$).

References

Akbar, G., C.A. Call, and R.D. Wiedmeier. 1995. Cattle dungpat microenvironmental effects on germination and establishment of crested wheatgrass. Arid Soil Res and Rehab. 9(4): 409-422.

Alpaca Registry, Inc. 2011. Registered Alpaca US. Online. Accessed 20 October 2011. http://www.alpacaregistry.com/public/reports/alpacaus.

Bang, H.S., J.H. Lee, O.S. Kwon, Y.E. Na, Y.S. Jang, and W.H. Kim. 2005. Effects of paracoprid dung beetles (Coleoptera: Scarabaeidae) on the growth of pasture herbage and on underlying soil. Appl. Soil Ecol. 29:165-171.

Bellows, B. 2001. Nutrient Cycling in Pastures. Available at https://attra.ncat.org/attra-pub/summaries/summary.php?pub=240 (verified 4 October 2011). ATTRA-NCAT, Butte, MT.

Bertone, M.A. 2004. Dung beetles (Coleoptera: Scarabaeidae and Geotrupidae) of North Carolina cattle pastures and their implications for pasture improvement. PhD Dissertation. North Carolina State Univ., Raleigh, North Carolina.

Bertone, M.A., Green, J.T., Washburn, S.P., Poore, M.H., and Watson, D.W. 2006. The contribution of tunneling dung beetles to pasture soil nutrition. Forage and Grazinglands. doi: 10.1094/FG-2006-0711-02-RS.

Bornemissza, G.F. 1970. Insectary studies on the control of dung breeding flies by the activity of the dung beetle, *Onthophagus gazella* F. (Coleoptera: Scarabaeinae). J. Aust. Ent. Soc. 9:31-41.

Bornemissza, G.F. and C.H. Williams. 1970. An effect of dung beetle activity on plant yield. Pedobiologia. 10:1-7.

Brown, J. C.H. Scholtz, J.L. Janeau, S. Grellier, and P. Podwojewski. 2010. Dung beetles (Coleoptera: Scarabaeidae) can improve soil hydrological properties. Appl. Soil Ecol. 46:9-16.

Bryan, R.P. 1973. The effects of dung beetle activity on the numbers of parasitic gastrointestinal helminth larvae recovered from pasture samples. Aust. J. Agric. Res. 24:161-168.

Bryan, R.P. 1976. The effect of the dung beetle, *Onthophagus gazella,* on the ecology of the infective larvae of gastrointestinal nematodes of cattle. Aust. J. Agric. Res. 27:567-564.

Chirico, J., S. Wiktelius, and P.J. Waller. 2003. Dung beetle activity and the development of trichostrongylid eggs into infective larvae in cattle faeces. Vet. Parasitol. 118:157-163.

Dalrymple, R.L. 1993. Crabgrass for high quality, high production, warm season forage. Small Farm Today. 10(1):14-15.

Dalrymple, R.L. 1994. A summary of research and demonstration about using crabgrass as a forage. Pub. No. CG-83. Noble Foundation, Ardmore, OK.

Donohue, S.J., and S.E. Heckendorn. 1994. Soil test recommendations for Virginia. Virginia Cooperative Extension, VPI and SU, Blacksburg, VA.

Fincher, G.T. 1981. The potential value of dung beetles in pasture ecosystems. J. Georgia Entomol. Soc. 16(2):316-333.

Fincher, G.T., W.G. Monson, and G.W. Burton. 1981. Effects of cattle feces rapidly buried by dung beetles on yield and quality of coastal crabgrass. Agron. J. 73:775-779.

Gittings, T., P.S. Giller, and G. Stakelum. 1994. Dung decomposition in contrasting temperate pastures in relation to dung beetle and earthworm activity. Pedobiologia 38:455-474.

Gökbulak, F. 2009. Influence of seed location and planting depth on seedling establishment in cattle dungpats. Grassland Sci. 55(1): 23-28.

Harris, R.L., E.H. Ilcken, R.R. Blume, and D.D. Oehler. 1980. The effects of horn fly larvae and dung beetles on ammonia loss from bovine dung. The Southwestern Entomol. 5(2):104-106.

Hunt, J. and L.W. Simmons, 2002. Behavioural dynamics of biparental care in the dung beetle *Onthophagus taurus*. Anim. Behav. 64(1):65-75.

Lastro, E. 2006. Dung beetles (Coleoptera: Scarabaeidae and Geotrupidae) in North Carolina Pasture Ecosystems. M.S. Thesis. North Carolina State Univ., Raleigh, North Carolina.

Lindquist, A.W. 1933. Amounts of dung buried and soil excavated by certain Coprini (Scarabaeidae). J. Kansas Entomol. Soc. 6(4):109-125.

McGregor, B.A. 2002. Comparative productivity and grazing behaviour of Huacaya alpacas and Peppin Merino sheep grazed on annual pastures. Small Rum. Res. 44:219-232.

McGregor, B.A. and A.J. Brown. 2010. Soil nutrient accumulation in alpaca latrine sites. Small Rum. Res. 94:17-24.

McLean, E.O. 1982. Soil pH and lime requirement. p. 199-224. *In* A.L. Page et al. (ed.) Methods of Soil Analysis, Part 2, 2nd ed. Agron. Mongr. 9. ASA, SSSA, Madison, WI.

Mehlich, A. 1953. Determination of P, Ca, Mg, K, Na, and NH4. North Carolina Soil Test Division (Mimeo 1953).

Noller, C.H. and C.L. Rhykerd. 1974. Relationship of Nitrogen Fertilization and Chemical Composition of Forage to Animal Health and Performance. p. 363-394. *In* D.A. Mays (ed.) Forage Fertilization. ASA, CSSA, and SSSA, Madison, WI.

Teutsch, C.D., J.H. Fike, and W.M. Tilson. 2005. Nitrogen fertilization rate and application timing effects on the nutritive value and digestibility of crabgrass. Forage and Grazinglands. doi: 10.1094/FG-2005-0614-01-RS.

Waghorn, T.S., D.M. Leathwick, L.Y. Chen, R.A.J. Gray, and R.A. Skipp. 2002. Influence of nematophagous fungi, earthworms and dung burial on development of the free-living stages of *Ostertagia (Teladorsagia) circumcincta* in New Zealand. Vet. Parasitol. 104:119-129.

Yamada, D., O. Imura, K. Shi, and T. Shibuya. 2007. Effect of tunneler dung beetles on cattle dung decomposition, soil nutrients and herbage growth. Japanese Soc. Grassland Sci. 53:121-129.

CHAPTER V

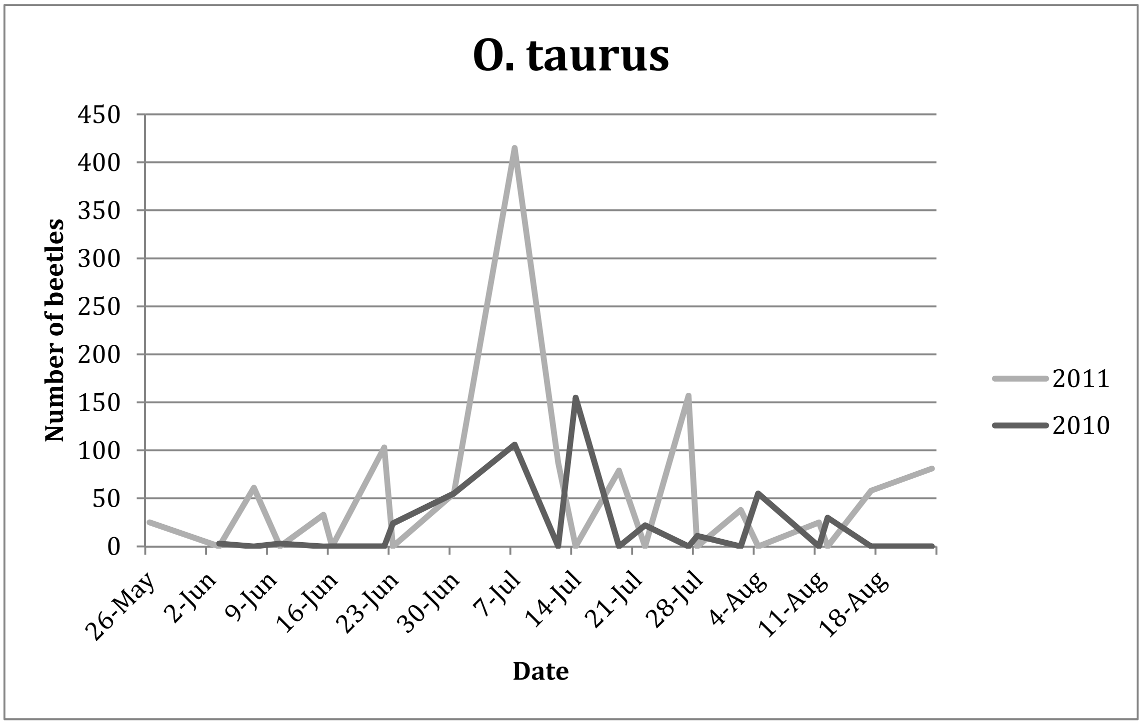
Summary and Conclusion

Alpacas continue to gain popularity in the US with a potentially viable fiber market developing. Unfortunately, most pasture and nutritional management recommendations are based on other ruminants. Strong nutrient cycles in grazing systems can reduce production costs and increase profits. Dung beetles have been shown to enhance nutrient cycling and forage growth in cattle pastures and they may be beneficial to alpaca pastures as well, although no research has yet explored these benefits.

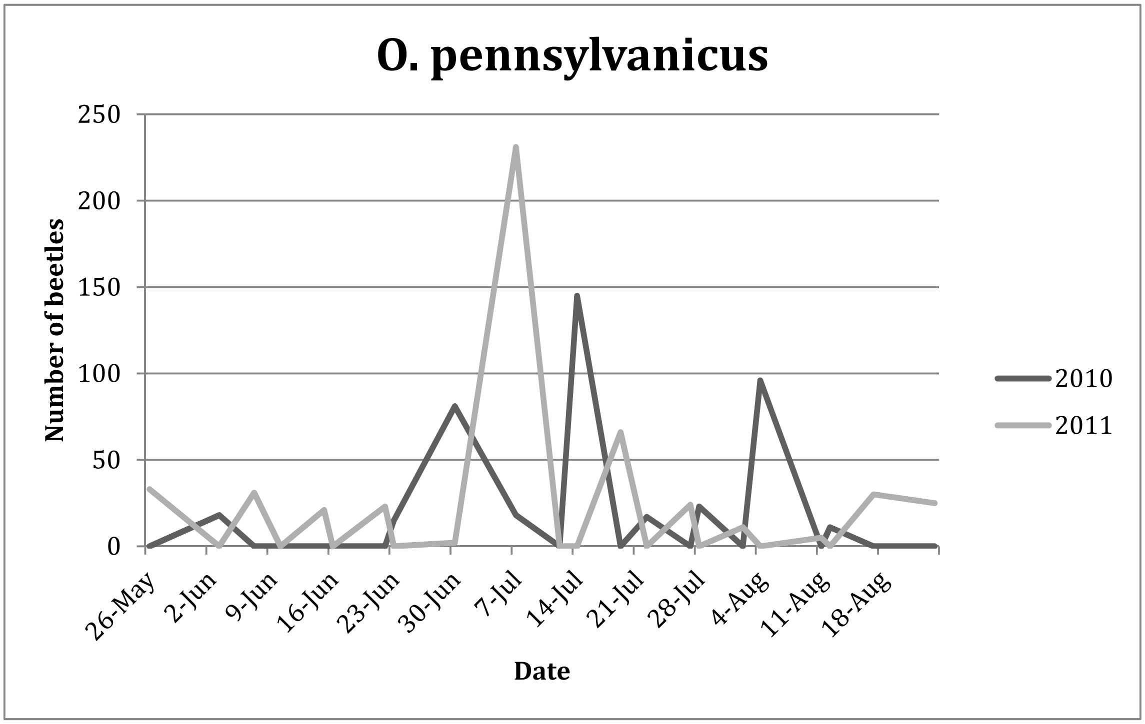
Eleven species of dung beetles were collected at the alpaca unit at VSU in Petersburg, VA from late May through late August in 2010 and 2011. The species collected were *Onthophagus taurus* Schreber, *O. pennsylvanicus* Harold, *O. hecate hecate* Panzer, *Copris minutus* Drury, *Phanaeus vindex* MacLeay, *Dichotomius carolinus* Linnaeus, *Sphaeridium scarabaeoides* Linnaeus, *Aphodius erraticus* Linnaeus, *A. fimetarius* Linnaeus, *A. (Nialaphodius) nigrita* Fabricius, *and A. (Labarrus) lividus* Olivier. The most abundant species in both years was *O. taurus*, which was 43% of the population in 2010 and 59% in 2011. *O. pennsylvanicus* was the second most abundant in both years with 39% and 24% of the population in 2010 and 2011, respectively. Native species represented 51% of the population in 2010, and 27% in 2011. Paracoprid beetles were dominant in both years, representing 94% and 86% of the populations in 2010 and 2011, respectively. Using Shannon's Diversity Index, the diversity of the dung beetle population was greater in 2010 than in 2011. Despite large differences in seasonal rainfall between years (9.60 cm in 2010 and 38.15 cm in 2011) and average temperatures being 2.0° C higher in 2010, the percent similarity in the dung beetle populations between years was high at 75.6%. This collection is evidence that diverse and abundant dung beetle populations exist in alpaca pastures in the mid-Atlantic region of the U.S.

To assess the benefits of dung beetles in grazing systems for alpacas, a greenhouse study was conducted. Treatments included the addition of 5 pairs of the most abundant dung beetle species, *O. taurus*, a field colonization of dung beetles, dung only, a no dung control, and three N rate treatments. The collection data was used to estimate the dung beetle population active in the field colonization treatment of the greenhouse study. Approximately six species of dung beetles colonized the pots in the field treatment, and resulted in significantly higher yields in the first harvest than the dung only and no dung control treatments. The addition of five pairs of *O. taurus* beetles significantly increased the yield over the control, but not over the dung only treatment. Overall, *O. taurus* increased forage yield by 10% over the control, while the field colonization increased yield by 14%. There were no treatment effects on soil nutrients, and there was little effect on forage nutritive value. A positive trend was seen with increasing N rate and yield. The PAN for the dung only and dung beetle treatments was estimated to be 76.0, 87.9, and 126.4 kg ha^{-1} for the dung only, *O. taurus*, and field colonization treatments, respectively. Unfortunately, communal dunging behavior of alpacas results in high concentrations of nutrients in small areas and remaining grazing areas do not benefit from the recycling of excreted nutrients. Even with an abundant dung beetle population and a diverse soil ecosystem, there is low efficiency in nutrient cycling without an even distribution of animal excreta. Management practices that improve the nutrient distribution in alpaca pastures are essential for utilizing the benefits of alpaca dung and the activity of soil organisms. The results of this study indicate that the addition of dung beetles in alpaca pastures can enhance forage growth given even manure distribution. Dung beetles, however, are only one component of a complex soil ecosystem that must be managed simultaneously for a productive and profitable pasture system.

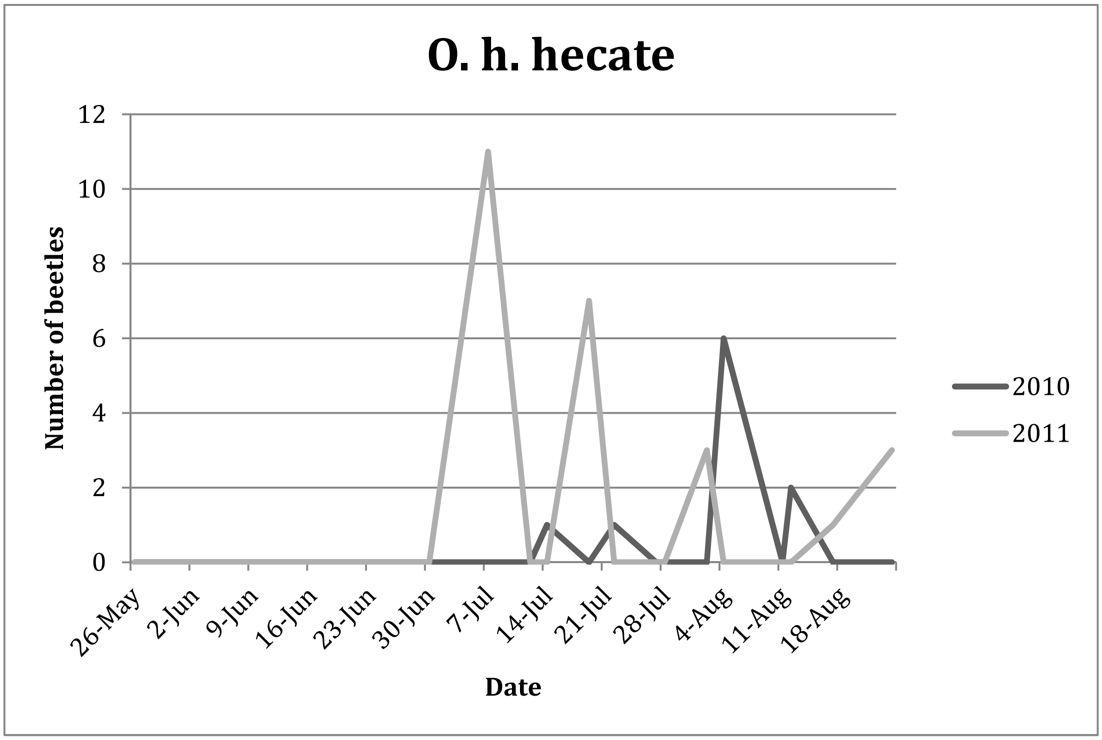
Appendix: Season Abundance of Dung Beetle Species



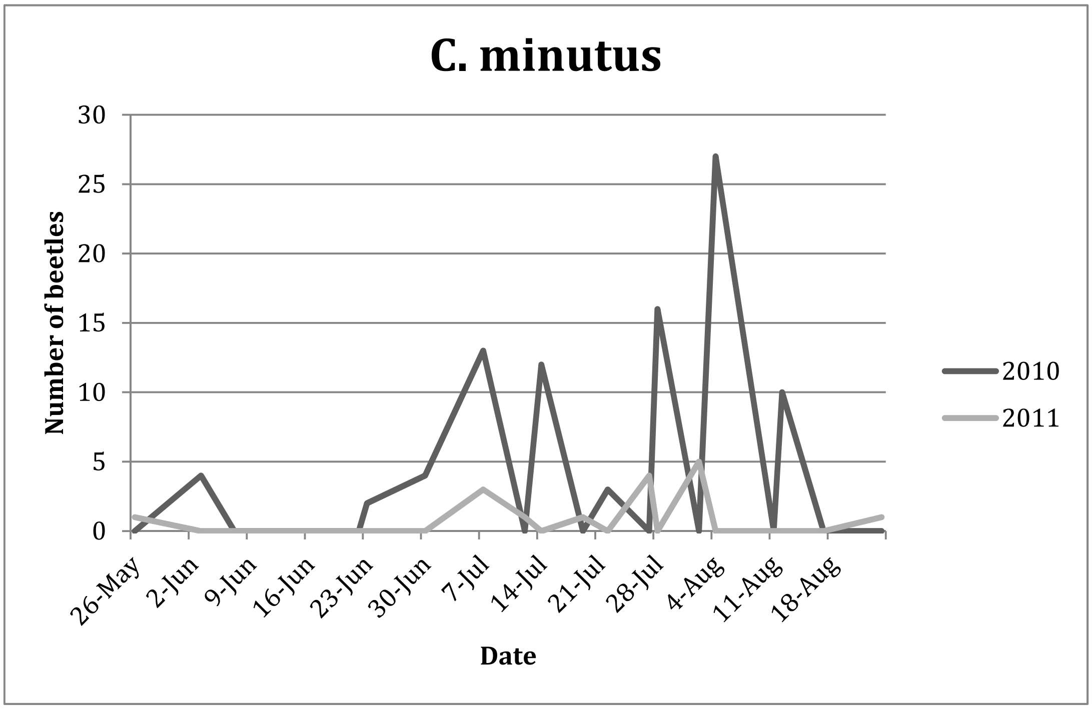
A- Seasonal abundance of *O. taurus* in 2010 and 2011.



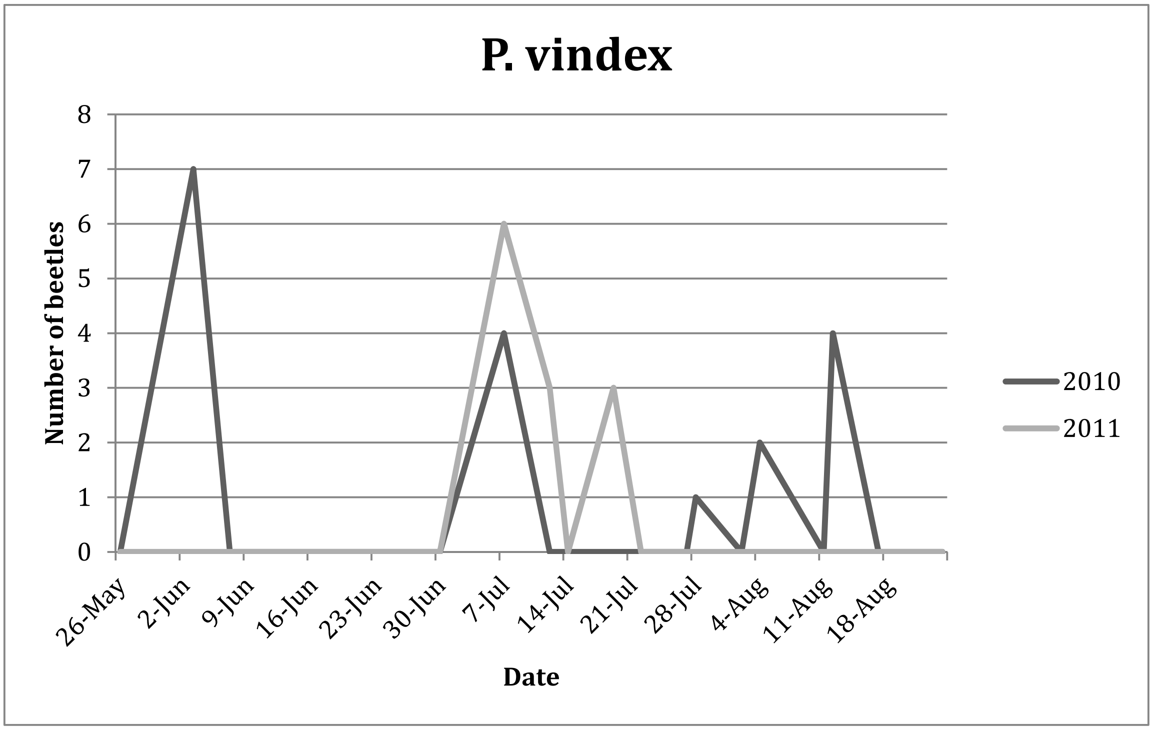
B- Seasonal abundance of *O. pennsylvanicus* in 2010 and 2011.



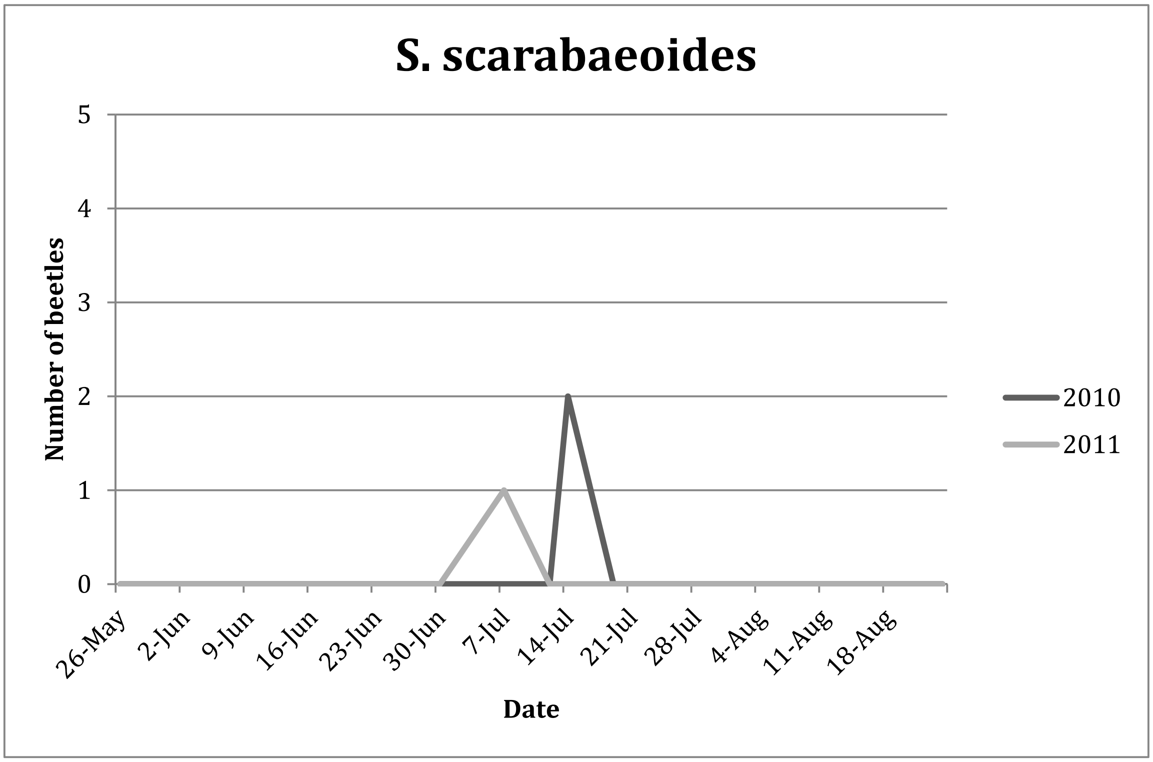
C- Seasonal abundance of *O. h. hecate* in 2010 and 2011.



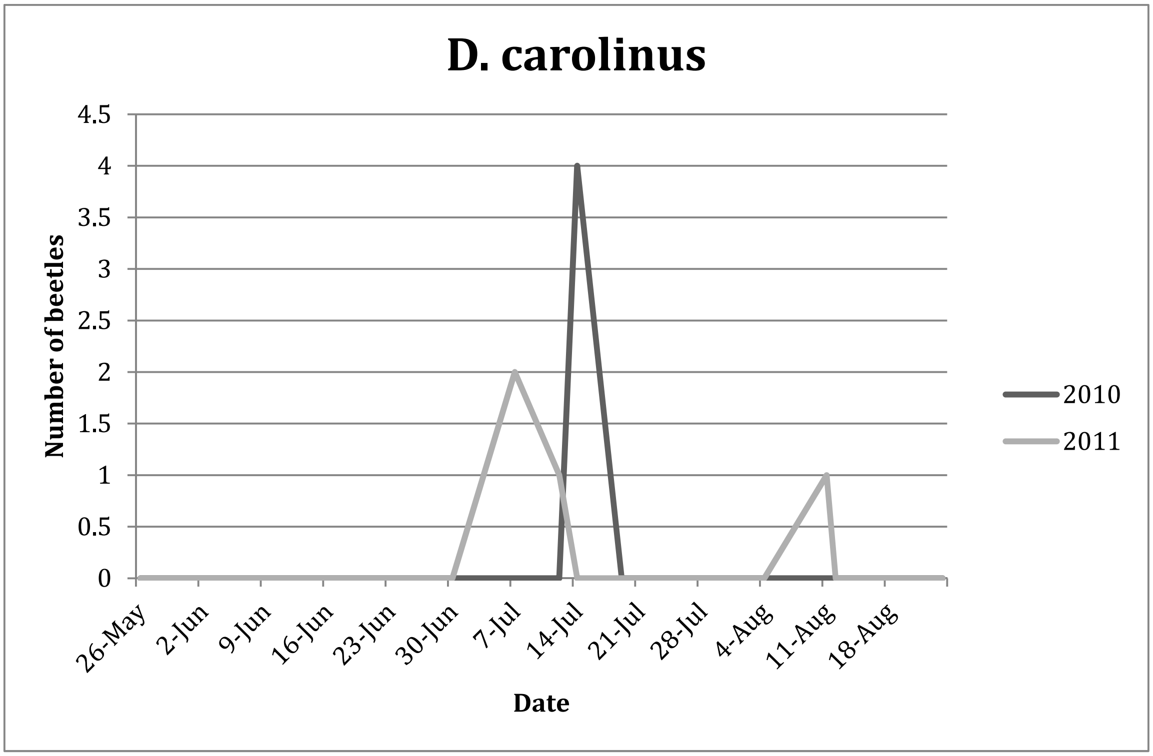
D- Seasonal abundance of *C. minutus* in 2010 and 2011.



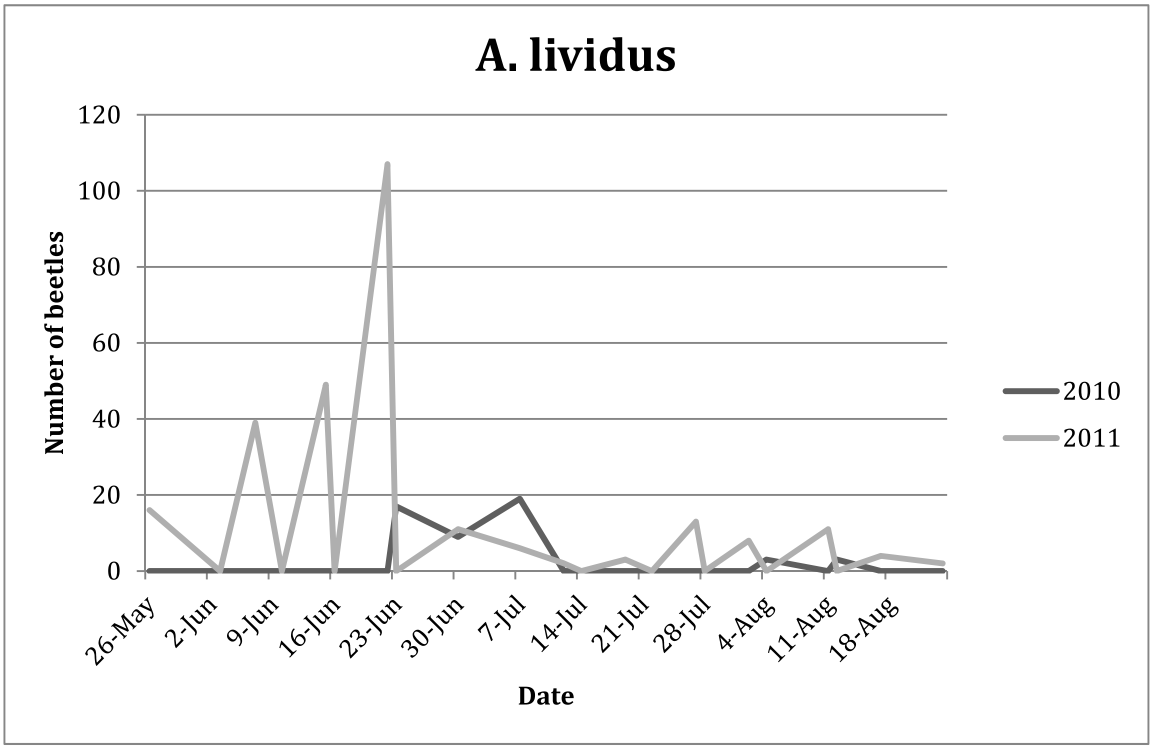
E- Seasonal abundance of *P. vindex* in 2010 and 2011.



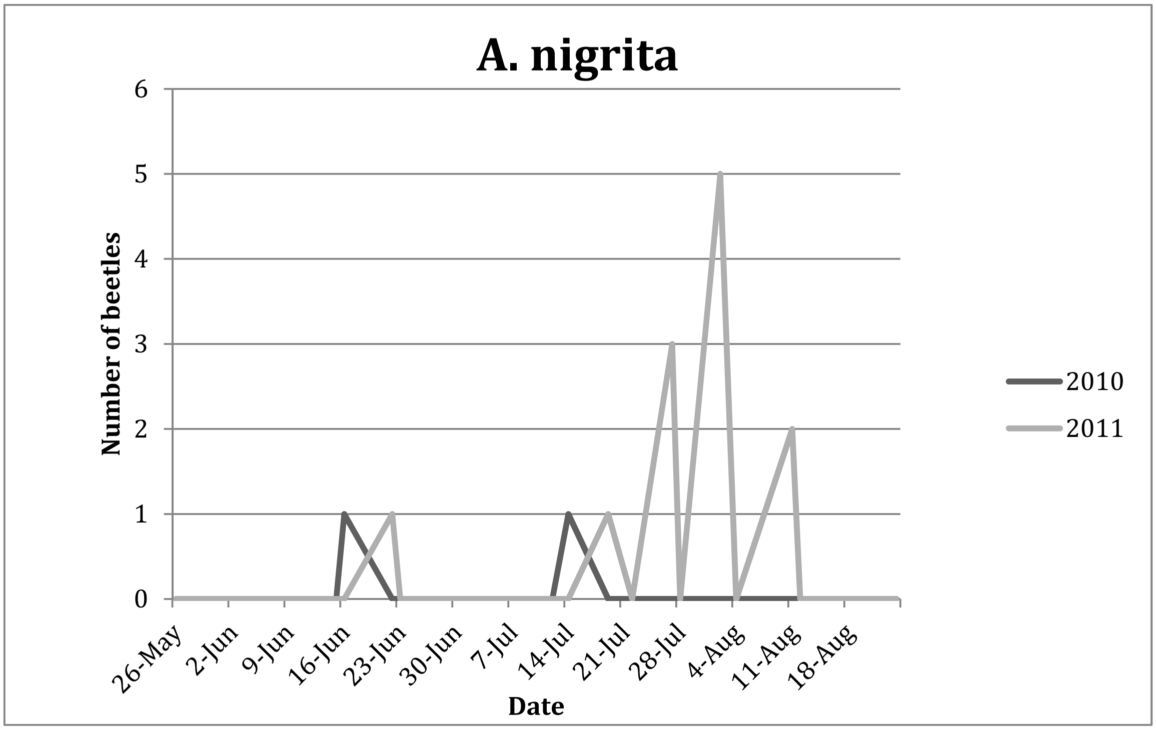
F- Seasonal abundance of *S. scarabaeoides* in 2010 and 2011.



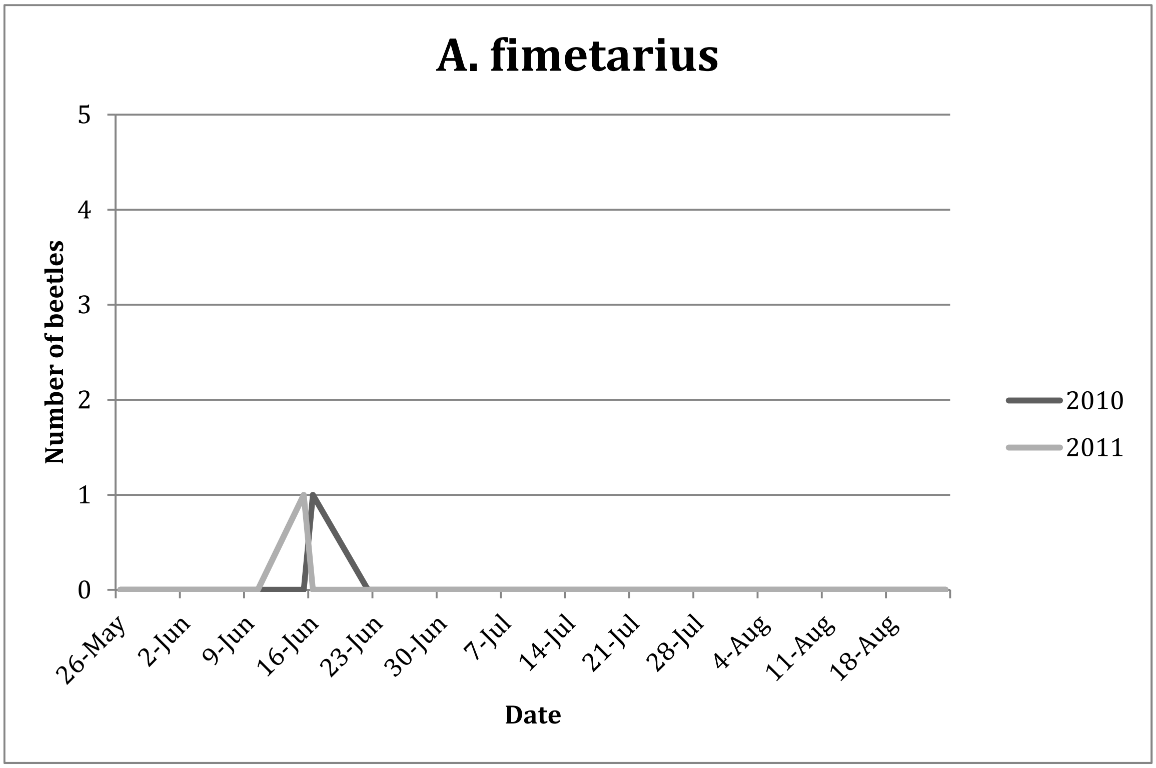
G- Seasonal abundance of *D. carolinus* in 2010 and 2011.



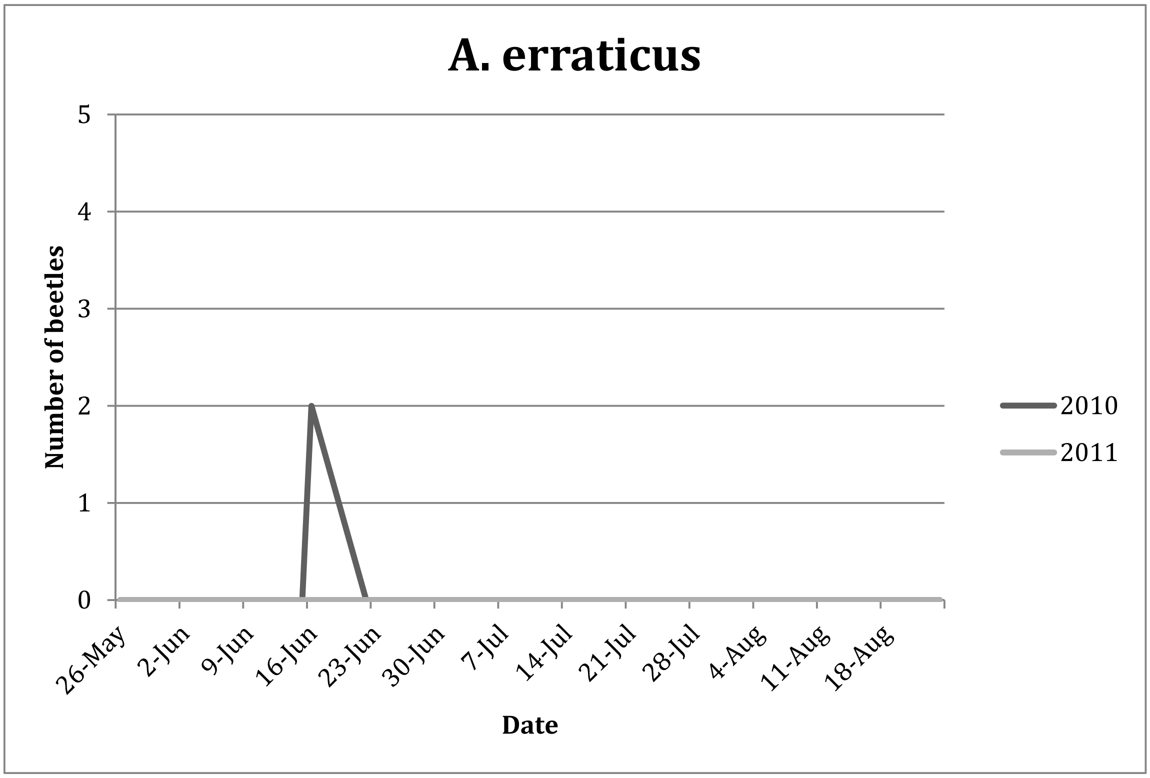
H- Seasonal abundance of *A. lividus* in 2010 and 2011.



I- Seasonal abundance of *A. nigrita* in 2010 and 2011.



J-Seasonal abundance of *A. fimetarius* in 2010 and 2011.



K- Seasonal abundance of *A. erraticus* in 2010 and 2011.