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Damage from mole crickets can be quite severe despite efforts to control them. Research at North Carolina State University sheds light on mole cricket's burrowing behavior.

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PURPOSE

The purpose of *USGA Turfgrass and Environmental Research Online* is to effectively communicate the results of research projects funded under USGA's Turfgrass and Environmental Research Program to all who can benefit from such knowledge. Since 1983, the USGA has funded more than 215 projects at a cost of $21 million. The private, non-profit research program provides funding opportunities to university faculty interested in working on environmental and turf management problems affecting golf courses. The outstanding playing conditions of today's golf courses are a direct result of ***using science to benefit golf***.

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Improving Mole Cricket Management by Targeting Their Weaknesses

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SUMMARY

Understanding insect behavior is a key component of any control strategy. Research was conducted at North Carolina State University and Cornell University to elucidate behavioral characteristics of mole crickets.

- Field and greenhouse stdies were conducted to elucidate the behavior of soil-inhabiting mole crickets and to develop a model to forecast mole cricket egg hatch.
- Monitoring over a three-year period did not establish a strong relationship between degree-day accumulation and egg hatch, development, or mating flight patterns.
- Soil moisture significantly affects timing and intensity of mole cricket egg laying.
- Research showed a strong relationship between the presence of adults in the spring in a specific area and subsequent outbreaks of nymphs and turf damage later in the summer.
- Slight increases in soil clay or silt content were generally associated with reduced mole cricket abundance.
- Tunneling of root-feeding tawny mole cricket produced a characteristic "Y-shaped" pattern and an avoidance behavior to insecticide-treated soil, or soil that has been treated with spores of entomopathogenic fungi.

Throughout much of the southeastern United States there are two species of mole crickets, the tawny mole cricket (*Scapteriscus vicinus*) and the southern mole cricket (*S. borellii*) that rank among the most devastating turfgrass insect pests in the world (Figure 1). The tawny mole cricket is primarily a root feeder, while the southern mole cricket is a predator of other soil arthropods (insects), but still damages turf damage by extensive tunneling.

The cost of control and the impact of damage often is measured in tens of thousands of dollars per golf course in many areas. Similar to many other serious insect pests, neither of these pests are native to the U. S., but were introduced

Figure 1. The southern (top) and tawny (bottom) mole crickets are the most serious soil insect pest in the southeastern United States.

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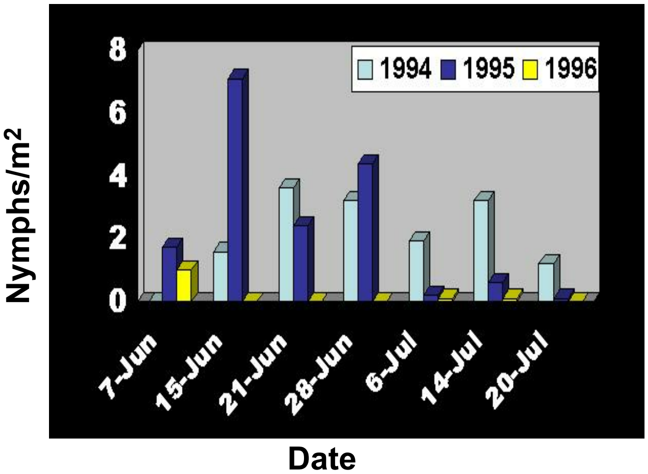

Figure 2. Mole cricket flight data in the spring show considerable variation from one week to the next.

to several locations along the Southeast coast in the early 1900s. Such introductions often allow the insects to rapidly expand in the absence of natural enemies. Since that time, they have migrated northward well into North Carolina and westward to eastern Texas and a few other isolated locations in warm climate areas of the U. S. Soil type and temperature limit much additional spread, but a few isolated infestations are also showing up in the southwestern United States.

The high costs associated with controlling mole crickets, the lack of consistent and effective control following insecticide application, and the relatively poor understanding of mole cricket ecology and behavior resulted in a proposal to the USGA Green Section Research Committee in 1992. A collaborative effort was established combining the applied research program on mole crickets at North Carolina State University under the direction of Dr. Rick L. Brandenburg and the soil insect ecology program directed by the late Dr. Mike Villani at Cornell University.

These two scientists and their research teams were fortunate to receive funding from USGA, and, for the next seven years, embarked on an ambitious program to better understand the biology, ecology and behavior of this most troublesome turfgrass insect pest. The intent was to develop better and more effective management programs based upon this enhanced knowledge base. The research program focused on several field and laboratory research projects. Each of these projects was targeted toward developing information that would directly compliment economically and environmentally sound mole cricket management programs.

Field Research

Field research was conducted on several golf courses in New Hanover and Brunswick counties along the southeastern coast of North Carolina. Additional studies were conducted in laboratories and greenhouses at North Carolina State University in Raleigh, N. C. and laboratories at the New York Agricultural Experiment Station at Cornell University in Geneva, NY.

Field studies to monitor mole cricket development and to develop an equation to forecast or predict mole cricket egg hatch was initiated early in the research program during 1992. Such studies can be useful to help time the implementation of control strategies and allow superintendents to be more efficient in their monitoring and scouting programs. Acoustic sound traps that synthetically produced the mating call of the male mole cricket were used to monitor mating flights. These electric sound generators were placed at two golf courses in Brunswick County. In addition, a network of automated soil and air temperature recording units were installed throughout the two-county area to monitor degree-day accumulation.

Course fairways were monitored weekly for the presence of mole crickets from late spring

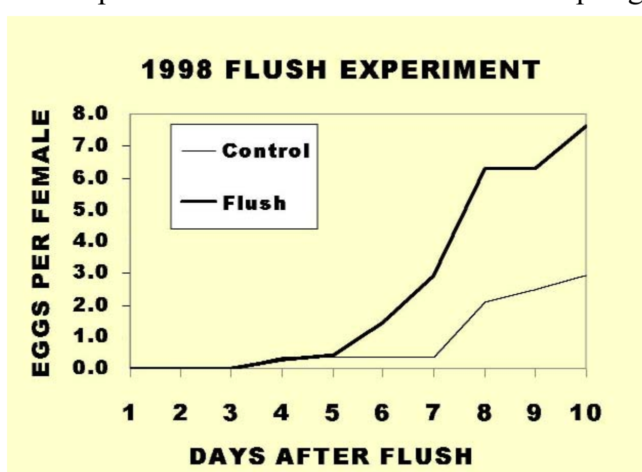

Figure 3. The effect of a simulated rain (flush of water) on mole cricket egg laying

to late summer. Intensive sampling consisted of using a 2% soapy water solution applied to square meter areas to bring mole crickets to the surface. Crickets were collected, returned to the laboratory, and recorded for species, size, and stage of growth. These data provided indications of egg hatch and cricket development as related to soil and air temperature. Monitoring over a three-year period provided situations with significant variations in degree-day accumulations, but did not establish a strong relationship with cricket egg hatch, development, or mating flight patterns.

Subsequent greenhouse evaluations at North Carolina State University determined that soil moisture plays a significant role in the egg laying process. Soil moisture affects the timing and intensity of mole cricket egg laying. Mole crickets prefer adequate soil moisture if they are to lay their eggs (Fig. 3). In fact, good soil moisture is required to prevent egg desiccation and to ensure survival of the small nymphs. There appears to be an important interaction between soil moisture and soil temperature that influences mole cricket development each year as well as the sites of infestation. Similar studies conducted in South Africa found a similar soil moisture response in that egg laying was related to the onset of summer rains.

Additional studies sought to more clearly define turf areas that could be considered at high risk for mole crickets. Such information could be useful to help direct scouting efforts to those high-risk areas. Research focused on the mole cricket abundance as influenced by soil moisture, various soil parameters, and topography. In addition, the relationship between the presence of adults in the spring and the subsequent outbreaks of the next generation of crickets in late summer was investigated.

The intensity of adult abundance was measured in the spring through a standardized grid rating system. A wide range of turf areas were monitored including those with little or no damage. Soapy water flushes were then used in the same areas late in the summer to determine the abundance of recently hatched mole cricket nymphs. Soil samples were taken weekly and soil moisture, texture, silt and clay content, as well as pH and organic matter were determined. General observations on topography were also noted.

Figure 4. A typical fiberglass resin casting of a tawny mole cricket with "Y" shaped entrance.

Our research shows a strong relationship between the presence of adults in the spring in a specific area and subsequent outbreaks of nymphs and turf damage later in the summer. This correlation is important since virtually all conventional insecticides are most effective when applied against small mole cricket nymphs. This timing will be long before obvious surface damage is visible. An understanding of this relationship between spring damage from adults and late summer damage from nymphs may allow a superintendent to map areas of adult damage in the spring and strategically apply insecticides in those locations during the summer as egg hatch occurs. This results in a cost-effective management program. Our studies indicate that once surface damage becomes visible, damage can double every 7-10 days.

Our studies also provided preliminary indications concerning the relationship of certain soil conditions and mole cricket abundance. Of

Figure 5. Fiberglass resin casting of an African mole cricket "Y" shaped tunnel in clay soils in South Africa.

greatest importance appears to be clay and silt content. Slight increases in clay or silt content of the soil were generally associated with reduced mole cricket abundance. While this relationship needs to be studied more closely, it does indicate possible management options. One is that certain areas may be defined as "high risk" based on soil characteristics. Such information could be useful in managing these pests. Another options may be in the use of organic soil amendments to modify soil preferences by the crickets

Research investigating the impact of irrigation, both before and after the application of insecticides, proved quite interesting. Large plots (50 ft. X 50 ft.) were established and subjected to various treatments and irrigation regimens. Treatments included no irrigation and both pre- and post-treatment irrigation on replicated plots as well as immediate vs. delayed irrigation and different irrigation amounts.

When the effects of these irrigation schedules were studied in conjunction with the use of several synthetic pyrethroid insecticides, the results were difficult to clearly understand. More irrigation water did not necessarily improve control and in some cases reduced control. Immediate irrigation seemed to reduce control as well. The use of both pre- and post-irrigation did improve control as compared to no irrigation, or pre- or post-irrigation alone. Two factors possibly added to this inconsistency. One is that as more water was applied (as either pre- or post-treatment irrigation), surface activity of the mole cricket increased in spite of the insecticide. However, the extent to which surface activity increased with increasing soil moisture was difficult to assess in this experiment as it was designed.

Another important factor adding to inconsistent control is an avoidance behavior of the mole crickets when an insecticide is applied to the soil. The exact nature of this avoidance is not well understood, nor has the degree to which it occurs in the field been fully explored, but irrigation could influence this behavior. However, reverse-rate responses in pesticide field testing trials are not uncommon. In other words, due to the insects' ability to detect and avoid the insecticide, higher insecticide application rates sometimes result in less control of the pests.

The field behavior of mole crickets was examined by creating castings of cricket tunnels with the use of a fiberglass resin. The resin, commonly used for auto body repairs, provided an easy to pour material that flowed smoothly into the tunnels in the soil and hardened quickly with the addition of a catalyst. The casting material formed a lightweight, durable material that could be easily excavated from the soil. The fiberglass resin also often encased the cricket occupying the tunnel making species identification easy.

Tunnels for the root-feeding tawny mole cricket almost always produced the "Y" shaped castings consistent with those observed in the laboratory soil radiographs. Studies conducted in South Africa of a species (*Gryllotalpa africana*) that also feeds on turfgrass roots had a very similar tunnel structure even though the soil was a heavy clay as compared to the sandy soil in the southeastern U. S. The structure recovered from the predatory southern mole cricket consisted of a meandering type of tunnel that might be associated with general searching in the soil. Castings from this species of mole crickets were also consistent with radiographs taken in the laboratory. The castings document a consistent tunneling pattern for an individual species and marked differences between the two species. These are obviously related to the general diet of the two species and to the behavior required to meet those dietary needs.

Greenhouse studies of field-collected crickets also indicate differences in response and possible susceptibility to specific insecticides by the two species. The actual effect of behavioral differences and individual cricket susceptibility to contact with a particular insecticide needs further investigation. These species differences, in addition to soil type and climate, may account for the variability in product performance often observed by superintendents in a specific region.

An additional area of research focused on the use of a fungal pathogen to help add insight into the findings of specific laboratory experiments. Several strains of the pathogen *Beauveria bassiana*, were applied for mole cricket control on golf course fairways and the effect on the population was monitored. Treatments included several strains of this pathogen applied with both surface and subsurface application equipment.

The results of their trials are not impressive in terms of level of control typically desired by golf course superintendents. However, the study does provide insight into the use of such control agents. The use of subsurface application equipment appears to improve the efficacy of these products, possibly by reducing the likelihood of exposure to sunlight or desiccation of the fungal spores.

Laboratory research

To further our understanding of the impact of environmental factors and disease on mole cricket, a clear picture of 'typical' tawny mole cricket and southern mole cricket behavior was necessary. Studies were initiated using radiographic technology (x-rays) to visualize the movement and feeding patterns of both tawny mole cricket and southern mole cricket in the soil matrix. Mole crickets were placed in plexiglass soil arenas (1.5 x 12 x 15 inches). Through the placement of a small lead tag on each cricket, tunnel construction and cricket movement in the tunnel could be monitored over extended periods of time.

A series of radiographs indicate a consistent behavior of a single late-instar tawny mole cricket nymph. This nymph produces a characteristic "Y" shaped tunnel (similar to that observed in the field with the fiberglass castings) that allows two escape routes to the surface and down into the soil to escape predators including larger southern mole crickets, and a long tunnel into the soil profile that most likely aids in thermal and water regulation.

Tawny mole crickets typically feed at the root/soil interface between the 'Y' arms and are

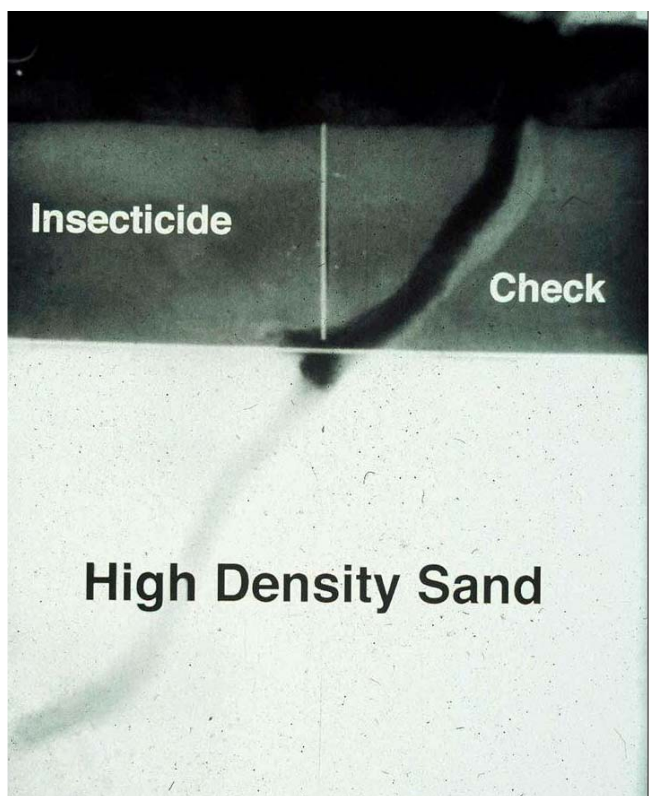

Figure 6. Apparent avoidance behavior of a tawny mole cricket to insecticide-treated soil as viewed with an X-ray image.

Figure 7. Complexity of mole cricket tunneling as documented by wax castings in the laboratory.

therefore always near an escape route. As tawny mole crickets grow, their tunnels widen and extend further into the soil profile suggesting a possible cause for the difficulty in bringing older crickets to the surface through soap flushes and baits. Crickets also seem to maintain their tunnel system, rebuilding collapsed tunnels over time. The 'Y' tunnel patterns of the tawny mole cricket do not seem to change in the presence of predatory southern mole crickets. Tawny mole crickets appear to 'wall-off' their tunnels when southern mole crickets are present, but further studies are needed to confirm this behavior.

By comparison, southern mole crickets will move as far from each other as possible when placed together in a chamber. This behavior suggests the presence and activity of a chemically-mediated avoidance behavior in this species. There is also an indication that mole crickets can detect and avoid conventional synthetic insecticides in the soil.

Additional studies on cricket behavior utilized arenas (12 x 20 x 8 inches) filled with moist sandy loam soil and topped with a commercial sod. A single tawny-mole cricket was placed in the arena and allowed to tunnel into the surface. At the end of seven days, each arena was sampled to determine the tunneling pattern of the cricket. To form a paraffin cast, the entrance to the mole cricket tunnel is located by looking for a disturbed area of turf. Solid paraffin wax is heated until liquid and poured slowly, to allow escape of air bubbles, into the tunnel entrance. After a short time (about 10 minutes) soil is carefully excavated from around the hardened wax and the full casting is retrieved (Fig. 7).

To reveal the tunnel of a single tawny mole cricket over a one-week period, soil was removed at 1.5-inch intervals from the surface to reveal the tunnel as it descended into the soil profile. Extensive tunneling at the root-soil interface was indicative of the cricket's food foraging behavior. Current studies with spray applications of the fungal pathogen *B. bassiana* indicate that reverse-rate responses often occur with higher rates. This may be the result of avoidance behavior associated with higher rates. Mole crickets detect and avoid formulations containing pathogenic fungi by remaining deep in the soil profile. This behavior allows mole crickets to avoid the fungal pathogen until it becomes inactive.

Laboratory studies were initiated to evaluate mole cricket behavior toward soil-borne, entomopathogenic (fungi that cause disease in insects) soil fungi and to evaluate the efficacy of subsurface and surface fungal applications. In these experiments, tawny mole crickets had no choice but to tunnel through a layer of fungal-treated sand in order to reach a sod food source. One late-instar tawny mole cricket was placed in each arena and allowed to tunnel for one hour before strips of sod were placed on top of the sand. After four days, the sod was removed and two inches of fungal-treated sand was added to the surface of the sand. An equivalent layer of clean sand was added in control treatments.

Two hours after treatment, 40% of the tawny mole crickets in both treated and untreated arenas had tunneled through the treatment layer and returned to the surface. After three and six days, 60% of treated and 80% of untreated tawny mole crickets had tunneled through to the surface sod. The amount of tunneling in the treatment layer area was significantly lower in arenas treated with the entomopathogenic fungi compared to the arenas containing the clean sand layers. Tunneling in the untreated layer below the interface was not significantly different in any treatment.

Current greenhouse studies show definite alterations in behavior of mole crickets kept in large containers with soil and sod. The amount of surface activity and the type of tunneling is markedly different in treated vs. untreated containers. Recent studies (2001-2002) in the greenhouse indicate mole crickets are repelled by the presence of these fungal spores and that spore persistence, repellency, and toxicity vary among strains.

These findings of avoidance behavior in mole crickets suggest that placement of fungal pathogens in the soil profile may influence the effectiveness of a product to control mole cricket damage to turf. The avoidance response seen in these experiments may be evidence of an evolutionary adaptation to avoid infected insects and areas of soil with high concentrations of fungal spores. Avoidance behavior may explain the inconsistent results found in the field with high doses and surface applications of fungal pathogens. Subsurface applications of fungal pathogens, however, may lengthen the time a pathogen remains viable compared to pathogen survival after surface application.

This field and laboratory research demonstrates the value of a good understanding of pest biology and ecology. These studies help us better understand the reasoning behind some of our strategies for mole cricket management. At the same time, they also reveal why mole crickets continue to be such a difficult pest to manage. Further studies will help ensure that our ability to cost effectively manage this serious pest.

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