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Effect of Surfaces on the Foraging Efficiency of *Solenopsis invicta* (Hymenoptera: Formicidae)

Lekhnath Kafle[1], Wen-Jer Wu[1], Robert K. Vander Meer[2], and Cheng-Jen Shih[1*]

[1] Department of Entomology, National Taiwan University, Taipei, Taiwan
[2] Agricultural Research Service, U.S. Department of Agriculture, Gainesville, Florida, USA

ABSTRACT

The effects of different surfaces on the foraging efficiency of *Solenopsis invicta* workers were observed. The results indicated that the foragers of *S. invicta* were more efficient when they foraged on hard and smooth plastic surfaces than on soil surfaces. Similarly, foragers of *S. invicta* were less efficient when they encountered obstacles such as gravel or grass. The foraging activities of the *S. invicta* workers were considerably less on grass than on gravel, and fire ant workers from wild colonies were more efficient than workers from one-year-old laboratory colonies.

Key words: *Solenopsis invicta*, forage, efficiency, surface

Introduction

In Asia, the red imported fire ant, *Solenopsis invicta,* was first detected in Taiwan in 2003 (Chen *et al.*, 2006; Hung *et al.*, 2006), in mainland China in 2004 (Xu *et al*., 2007), and in Hong Kong and Macao in 2005 (Zhang *et al*., 2007). After detecting *S. invicta*, a serious invasive insect pest, several techniques were used around the infested areas either to control their population or to limit its further expansion. To control *S. invicta* in a large area, toxic bait products are reported to be the most effective tool (Vogt *et al.*, 2003). From a management point of view the efficacy of toxic baits depends upon the foraging activities of *S. invicta,* because the bait product that is spread must be detected and carried back to the nest and be share with the nest mates in order to be effective. In order to fulfill these three steps, effective foraging by the ants is required.

Ants use chemical, visual and even magnetic cues to correctly orient themselves in their foraging environment. Some pheromone-trail-following ants readily correct their course when displaced by using their memory of environmental cues (landmarks and sun compass) (Jackson *et al*., 2004). For *S. invicta* temperature has been reported to be a major factor influencing their foraging activities. Especially their recruitment behavior is

*Correspondence address
e-mail: shihcj@ntu.edu.tw

highly affected by soil temperature (Traniello, 1989; Crist and Williams, 1999; Ruano *et al*., 1999). Besides temperature, other ecological factors also affect the fire ant's foraging activities, such as vegetation structure, food availability, food abundance, food predictability and distribution. In addition, rainfall and seasonal weather variations also affect the foraging activity of *S. invicta* (Vogt *et al*., 2003). In response to these factors, many ant species change their foraging strategies (Crist and MacMahon, 1991). However, the best way to evaluate the optimal foraging strategy of a colony is determined in terms of its effect on colony fitness (Ruano *et al*., 1999).

Generally, *S. invicta* foragers use an extensive system of foraging tunnels 2-7 cm below the soil surface. The exit holes of these tunnels are distributed throughout their foraging territory, such that the foragers need to travel for only a distance of approximately 0.5 m above ground to reach any point in their territory while foraging (Porter and Tschinkel, 1987). Therefore, materials on the ground may act as obstacles for the *S. invicta* foragers when they are foraging above ground. *S. invicta* can be found at riverbanks, public playgrounds, grasslands, agricultural fields or roadsides. In Taiwan, because of the higher topography and the diversity in land use, all of these above mentioned areas can be found within a short distance. These different sites all have a different surface texture and contain different physical obstacles for the foragers of *S. invicta*. These different surface textures and obstacles affect the foraging activity and the efficiency of *S. invicta.* Based on the above, this study aimed to observe the foraging efficiency of the workers of *S. invicta* on different surfaces under laboratory conditions.

Materials and Methods

Source of *S. invicta*

Solenopsis invicta colonies were collected from Hsinchu County (northern Taiwan). The area in which the fire ant mounds were distributed was fallow land covered with grasses and small gravels with a dry, rough surface texture. However, this characteristic is not crucial since fire ants can create mounds on any kind of soil. They can alter the physical as well as the biogeochemical properties of soils including increasing aeration and infiltration, altering soil pH, lowering surface soil bulk density, reducing organic matter and lowering of texture grade (Green *et al*., 1998; Seaman and Marino, 2003; Lafleur *et al*., 2005; DeFauw *et al*., 2008). After collection, the ants were separated from the soil by a water drip-out method (Chen, 2007) and reared under laboratory conditions as described by Kafle *et al*. (2008), for at least one week prior to the experiments. The laboratory ants were starved for 2 days prior to the experiments to ensure that their mid-gut was empty and that they were hungry enough to search for food (Furman and Gold, 2006; Kafle *et al*., 2009). The *S. invicta* colonies reared in the laboratory for one week were considered to be wild colonies, whereas the colonies reared in the laboratory for one year were considered as one-year-old colonies.

Foraging area, nest preparation and placement of the food lures

The procedures and criteria for the foraging area, nest preparation and bait placement were adapted from Kafle *et al.* (2008). A circular artificial foraging area, 40 cm in diameter x 17 cm in height (see Fig. 1a), was used in this study. The detailed arrangement of the artificial foraging area, including the artificial nest and bait placement, were the same as that of Kafle *et al.* (2008). Hotdog (ca. 1 g) was used as a food lure, and was kept on the half-cut plastic weighing plate and placed on four equidistant locations on the inside of the circular foraging area (Fig. 1c).

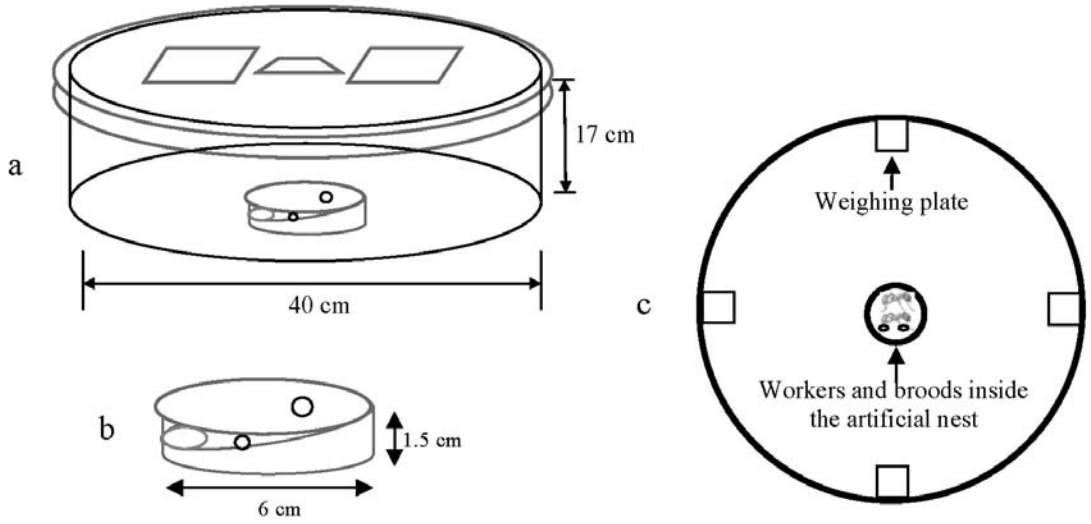

Fig. 1. Artificial foraging area (a), artificial nest (b), and food lure placement design (c) (adapted from Kafle *et al*., 2008).

Foraging surfaces

To determine the effect of the type of surface on the foraging activities of fire-ant workers, a smooth, hard, transparent plastic surface was used as the control surface. To prepare a soil surface, soil from a fire ant mound was collected from the field and ground into fine powder. Grinding the soil makes it easier and faster when preparing an artificial soil surface. The mound constructed by fire ants is a complex, dense network of narrow tunnels and nodules constructed of soil pellets mined from deeper soil levels (5-15 cm depth) linking deeper true subterranean chambers to the above ground portion of the fire ants' nest (Tschinkel, 2003; DeFauw *et al*., 2008).

A mixture of 500 g soil powder and 300 mL water was prepared and poured into the foraging area (Fig. 1a) to form a 5 cm deep layer on the control foraging surface. The best combination of soil and water for making an artificial soil surface for the present study was determined from an earlier study. The containers with wet soil were kept in the laboratory for 12 h to dry the foraging surface. A total of six combinations, each consisting of two surfaces and two obstacles (grasses or gravels) were prepared. They were; i) control surface, ii) control and gravels, iii) control and grasses, iv) soil only, v) soil and grasses, and finally vi) soil and gravels. Two obstacles, gravel with a length of (1.96 ± 0.14 cm, mean ± SE) and a width of (1.4 ± 0.12 cm, mean ± SE) (ca. 150 g), or small pieces of dried grass (*Panicum repens*) (ca. 2 cm) (15 g), were spread on the surface and was kept for 1 h to stabilize the ants' movements.

Effect of a surface on the foraging activity of *S. invicta*

To understand the effect of a surface on the foraging activity of *S. invicta* workers, 600 workers and 120 pieces of brood were placed together in the artificial nest of the foraging arena as described by Kafle *et al.* (2008). The number of fire ant workers visiting the hotdog food lures were recorded every 30 min for 390 min.

This study was replicated four times. All experiments were conducted at 27 ± 1°C and 50 ± 3% RH with 14h:10h light and the dark condition. Means were separated with Student-Newman-Keuls significant difference tests (SAS Institute, 2008).

Results

Foraging efficiency of wild and one year old colonies

The mean numbers of fire ant workers from one-year-old laboratory colonies and wild colonies feeding on hotdog lures were compared. The results revealed that the mean number of *S. invicta* workers from the wild colonies feeding on food lures (352 ± 22.43, mean ± SE) were significantly higher (p = 0.0001, F = 124.88, df = 1) than that of *S. invicta* workers from the one-year-old colonies (223.75 ± 12.57, mean ± SE) under laboratory conditions.

The effect of the type of surface on the foraging activity of *S. invicta* workers

When the ants were placed on the control foraging area with or without obstacles, the highest number of ants were observed feeding on food lures on the control surface without obstacles. This was followed by the control surfaces with gravels and then with grass as obstacles (p = 0.0009, F = 16.64, df = 2). Similarly, when the ants were placed on a soil surface without obstacles, or with gravels or grass as obstacles, a significantly higher number of ants were observed feeding on food lures placed on a soil surface without obstacles, followed by a soil surface with gravels and then with grass obstacles (p = 0.0003, F = 23.03, df = 2) (Table 1).

The foraging activities of fire ants between different surfaces without obstacles or with similar obstacles were also compared. When comparing the mean numbers of ants observed on two different surfaces without obstacles, a significantly higher numbers of ants were observed on the control surface than on the soil surfaces (p = 0.0001, F = 45.41, df = 1). Similarly, when comparing the mean numbers of ants observed on two different surfaces with gravel as an obstacle, a significant higher numbers of ants were observed on the control surface with gravel than on the soil surface with gravel (p = 0.0001, F = 124.88, df = 1). Furthermore, when comparing the mean number of ants observed on two different surfaces with grass as an obstacle, a significant higher number of ants were observed on the control surface with grass than on the soil surface with grass (p = 0.0009, F = 37.33, df = 1) (Table 1).

Discussion

The control surfaces, which were made of hard plastic sheets, were smooth and even. On the other hand, the soil surface was rough and uneven. Because of the rough soil surface, the movements of the fire ants might have been negatively affected. Similarly, fire ants use pheromone trails to guide the foragers

Table 1. Foraging activities of *Solenopsis invicta* on different foraging surfaces

	No. of ants (mean ± SE)*		
Surface	No obstacle	Gravels	Grasses
Control	223.75 ± 12.57aA	174.5 ± 6.56bA	124.5 ± 15.59cA
Soil	143 ± 20.03aB	84 ± 4.74bB	28.25 ± 2.29cB

*Means within the same column (upper case) and same row (lower case) followed by the same letter are not significantly different (p < 0.05) using SNK Test (SAS, 2008).

between nest and food (Jackson *et al*., 2004). A different foraging surface can cause a different response to the residual life of pheromones on the foraging trails. From the results of this study, it can be hypothesized that pheromones left on the foraging trails on a soil surface were depleted or weakened faster than those on the control surfaces. Because of the weakened or depleted signals, nests mates could not be guided into the right direction, making the foraging of the fire ants less efficient.

The physical obstacles also reduced the foraging efficiency of fire ants, in that the reduction produced by grass was higher than that of gravel. Gravel spread on the artificial foraging areas remained stable on the surface, while pieces of grass were always shaken and moved about when the fire ants foraged. Similarly, fire ant workers escaped having to go over the pebbles by creating an alternative foraging trail. However, ants were walking all over the grass and spread a wide trail on the artificial foraging areas. This spreading and crossing over of the grass possibly created a barrier to the foraging of the fire ants, and made them less efficient than when foraging on a surface with gravel obstacles. Finally, the amount of toxic bait or insecticide applied in the field to control fire ants were all the same for all fire ant infested areas without consideration of the type of obstacles (grass, gravel or both) in the areas. In addition, when either toxic baits or insecticide is applied the type of land is rarely taken into consideration. This study revealed that it is important to consider the presence or absence of obstacles and the type of obstacle before toxic bait or insecticide is applied. Although, *S. invicta* foragers use tunnels to travel around their territory, they still need to walk on the ground surface while foraging. Therefore, the surface area of a fire ant infested area plays a considerable role on the foraging activity of fire ants.

The fire ants from one-year-old laboratory colonies were less efficient than the wild fire ant colonies. The reason for this may be that laboratory colonies were always supplied with sufficient food. On the other hand, wild colonies always lived under food scarce conditions. They had to search for food for greater distances than the laboratory colonies. At the same time, rearing fire ants under artificial conditions might reduce their activeness and adaptability to new environments compared to the wild colonies. Several reports have observed the effects of weather, season, temperature or other physical environments on the foraging efficiency of fire ants (Porter and Tschinkel, 1987; Traniello, 1989; Vogt *et al*., 2003) but they all excluded the surface effects on foraging. This study showed that along with other environmental factors observed previously, the surface the fire ants forage on can affect their foraging efficiency. However, more in-depth studies need to be done both in the field and in the laboratory to understand the effects of both surface and obstacles on the foraging activity of *S. invicta* foragers under diverse field conditions in Taiwan.

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表面對入侵紅火蟻覓食效率的影響（膜翅目：蟻科）

Lekhnath Kafle[1]、吳文哲[1]、**Robert K. Vander Meer**[2]、石正人[1*]

[1] 國立台灣大學昆蟲學系　10673 台北市羅斯福路四段 113 巷 27 號

[2] Agricultural Research Service, U.S. Department of Agriculture, Gainesville, Florida 32608, USA

摘　要

本文探討不同的表面對入侵紅火蟻工蟻覓食效率的影響。火蟻在硬且平滑的塑膠表面的覓食效率高於土壤表面；同樣地，火蟻遇到砂礫或青草等障礙物時的覓食效率也較差，而且青草降低火蟻的覓食活動遠大於砂礫。此外，野外群落的火蟻工蟻的覓食效率比室內飼養一年的群落工蟻為佳。

關鍵詞：入侵紅火蟻、覓食、效率、表面。

*論文聯繫人
e-mail: shihcj@ntu.edu.tw