RECRUITMENT OF THE RED IMPORTED FIRE ANT, *SOLENOPSIS INVICTA*, TO SOYBEAN OIL BAITS

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ABSTRACT

A field investigation was conducted to compare the diel periodicity and rates of recruitment of the red imported fire ant, *Solenopsis invicta* Buren, to soybean oil presented in two forms. Bimodal patterns of recruitment were usually observed to corn cob particulates saturated with oil but not to cotton wicks saturated with oil. Recruitment to both rates was usually higher at night but not always significantly ($P \geq 0.05$) different from rates observed during the day. Significantly ($P \leq 0.05$) higher rates of recruitment occurred to the particulate oil bait relative to the liquid oil bait at most times studied. The size of ants recruited to the two baits varied significantly ($P \leq 0.05$); however, no consistent or explainable pattern in the size of ants recruited over each 24-hour period was observed for either bait. Ants of the media worker subcaste were generally recruited at significantly ($P \leq 0.05$) greater rates to both baits relative to minor and major workers. Standard multiple regression analyses revealed that changes in air and soil temperatures had a significant ($P \leq 0.05$) impact on recruitment; however, changes in air and soil moisture did not appear to influence rates of recruitment to the baits.

RESUMEN

Se condujo una investigacion en el campo para comparar la periocidad "diel" y los grados de obtener aceite de soya presentado en dos formas por la hormiga roja importada, *Solenopsis invicta* Buren. Se observó un patrón bi-modelo en la obtención de partículas de mazorca de maíz saturadas en aceite pero no en mechas de algodón saturadas en aceite. La obtención a ambos niveles usualmente fue más alta de noche, pero no siempre significativamente diferente ($P \geq 0.05$) de los grados observados durante el dia. La mayoría de las veces que se estudió, se obtuvo significantemente ($P \leq 0.05$) grados más alto de obtención ocurrido con trampas de cebo con partículas de aceite relativo a cebos de aceite líquido. El tamaño de las hormigas obtenidas en las dos trampas varió significantemente ($P \leq 0.05$), sin embargo no se observó un patrón explicable o consistente en el tamaño de las hormigas obtenidas durante un período de 24 horas en ninguna de las trampas. Hormigas trabajadoras de la sub-casta media fueron generalmente obtenidas en grados significantemente ($P \leq 0.05$) más altos relativo a trabajadoras menores y mayores hacia ambos cebos. La norma del análisis de regresión multiple reveló que cambios de temperatura en el aire y en la tierra tuvieron un impacto significante ($P \leq 0.05$) en lo obtención, sin em-

bargo, cambio en la humedad aire y de la tierra aparentemente no influyeron los grados de obtención de las trampas.

Introduction

The red imported fire ant, *Solenopsis invicta* Buren, has spread throughout a large portion of the Southeast after being introduced into the United States from South America (Lofgren et al. 1975). *S. invicta* is a highly territorial species (Wilson et al. 1971) that is characterized by the large size of its colonies (Lofgren et al. 1975) and the mass recruitment of worker ants to food sources (Wilson 1962). Efforts to control *S. invicta* populations have traditionally involved the use of soybean oil-insecticide mixtures impregnated on corn cob particles (Lofgren et al. 1975). Foraging workers retrieve particles that have been broadcast over infested areas or spread around the perimeter of *S. invicta* colonies. Since some currently used toxic baits are rapidly degraded (Apperson et al. 1984, Vander Meer et al. 1982), knowledge of recruitment activities would help to improve the timing of bait applications and thereby improve the efficiency of control programs.

The objectives of our investigation were: (1) to compare recruitment over a 24-hour period to two forms of soybean oil baits; and (2) to determine the impact of some meteorological and edaphic factors on *S. invicta* recruitment activities.

Methods and Materials

Experiments were conducted in a 6.1-ha field near Bolivia, Brunswick County, North Carolina, between May and July 1982, prior to the planting of soybeans (*Glycine max* (L.) Merr.). The field had been disked in the fall of 1981, and some weeds, primarily sicklepod (*Cassia obtusifolia* L.), Pennsylvania smartweed (*Polygonum pensylvanicum* L.), and morning glory (*Ipomea* spp.) were found across the field.

Baits

Once-refined soybean oil was used as bait. Soybean oil was chosen as a stationary, concentrated food source because it is readily accepted by *S. invicta* (Hays and Arant 1960, Lofgren et al. 1964) and is easily distributed on a particulate carrier (Lofgren et al. 1973). Once-refined soybean oil was presented in two forms: on a corncob grit carrier; and in one dram vials fitted with cotton wicks. The particulate bait was placed in a pile on a flat plastic dish 15 cm in diameter. The liquid bait was contained in 12 vials arranged in a circle and inserted horizontally to ca. one-half their length into holes punched near the bottom of a plastic container. This container was pushed down into the soil so that the wicks contacted the soil surface. These two bait stations were left in place throughout each 24-hour observation period.

Experimental Area and Placement of Baits

Sampling was carried out near two *S. invicta* mounds which were located adjacent to pine woods at the periphery of the field. The mounds were of

similar size (ca. 0.6 x 0.4 x 0.3 m high) and were ca. 115 m apart. A particulate oil bait was placed ca. 6 m away from one mound and a liquid oil bait was placed ca. 6 m from the other mound. On each successive sampling date, the bait stations were switched to the opposite mounds to preclude effects of hunger state, food preference or colony size upon recruitment rates. The liquid and particulate baits were placed in the field one hour before observations were initiated to allow ants to locate the baits and establish recruitment trails.

Observations

At the recruitment trail established to each bait station, a string was tied across the trail between two stakes about 1 m from each bait. Ants moving past this point, traveling toward the bait, were counted. Because the ant trail was usually disrupted by the approach of an observer, it was necessary to wait several minutes until regular traffic flow resumed before observations were made. Once the flow resumed, all ants passing under the string on their way to the bait were counted for 2 minutes. Counts were made every 4 hours, with a total of 7 counts made for each 24-hour period. A headlamp was used to make observations at night. A diel sampling was carried out on 5 dates. Observations for the first sampling date (May 27) were initiated at 0900 hrs, the second (June 2) at 1400 hrs, and third (June 15), fourth (June 28), and fifth (July 2) at 1600 hrs.

Some of the ants running on the recruitment trails were collected with an aspirator during each observation. These ants were brought back to the laboratory and their head capsule widths were measured to determine if there were any changes in the size of workers recruited to the baits over time. Voucher specimens of fire ants have been deposited in the Entomology Museum of North Carolina State University.

Abiotic and Edaphic Parameters

Measurements of air and soil temperature, relative humidity, and soil moisture for correlation with fire ant recruitment activities were taken following each observation period. Temperatures were measured with an Extech® Model 1200 digital thermometer, and all readings were taken close to the recruitment trail without disturbing the ants. Air temperature was measured ca. 3 cm above the soil surface and soil temperature was measured after pushing the probe just under the surface. A Bacharach® sling psychrometer was used to measure relative humidity. For moisture determinations, shallow soil samples were taken with a Hoffer sampler. The samples were weighed in the field immediately after collection to the nearest 0.1 g and then brought back to the laboratory and dried in an oven to a constant weight. Values for soil moisture were calculated on a percent dry weight basis. Temperature, soil moisture and relative humidity data were collected at each bait station.

Statistical Analyses

A contingency table was constructed for the numbers of ants counted running toward the 2 baits at the 7 time intervals on each and over all sampling dates. Chi-square tests were carried out to determine if the re-

cruitment rates to the baits varied independently and also to test the hypothesis of equal recruitment for the two baits at a given date. The partitioning of the chi-square for bait x date x time was accomplished by the FUNCAT procedure of the Statistical Analysis System (Helwig and Council 1979). Standard multiple regression procedures were used to determine effects of the temperature and moisture variables on recruitment rates to the baits.

Measurements of *S. invicta* head capsule width were grouped according to the worker subcaste classification of Wilson (1978). Chi-square tests were carried out to determine if the numbers of ants of each subcaste recruited to the two baits varied independently. Unless otherwise indicated, all statistical analyses were performed at the $P \leq 0.05$ level of significance.

Results and Discussion

Periodicity of Recruitment

Recruitment to the particulate bait exhibited a bimodal pattern on 4 of the 5 sampling dates (Fig. 1). When trials were initiated in the late afternoon, recruitment activity was observed to peak at night and again the following day. The opposite situation occurred when the trials were started in the morning or early afternoon. A bimodal pattern of recruitment to the liquid bait generally was not found. Movement of ants along the

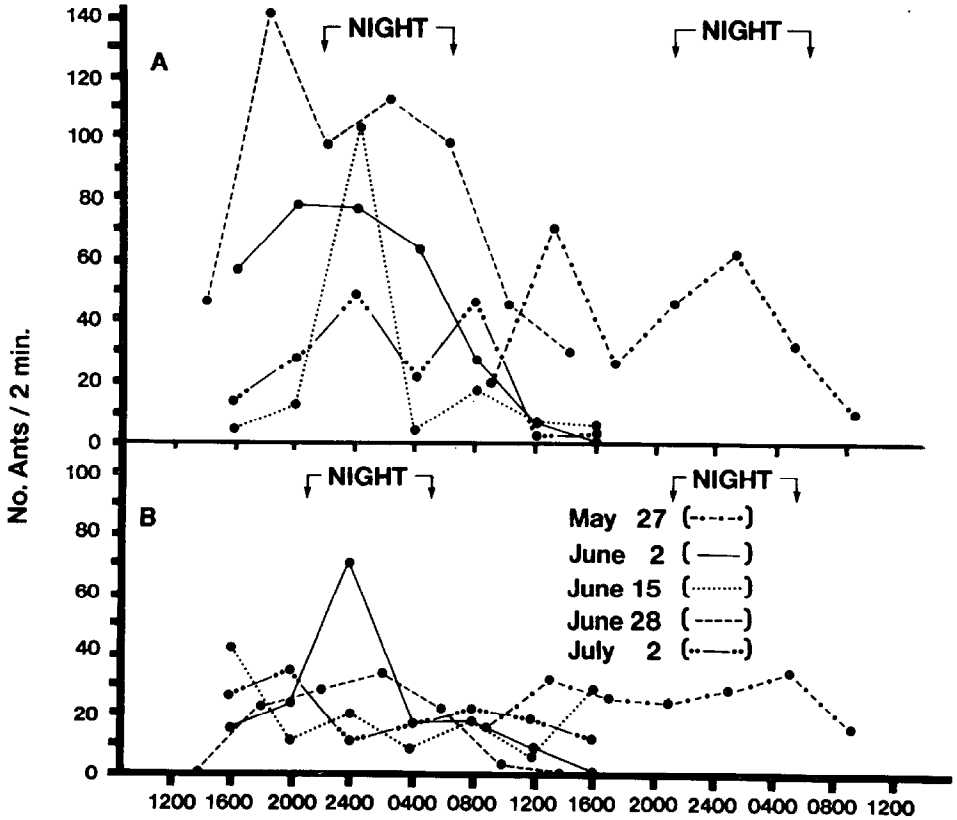

Fig. 1. Diel recruitment of *S. invicta* to particulate (A) and liquid (B) soybean oil baits.

recruitment trails decreased at the end of the 24-hour observation periods, sometimes ceasing altogether regardless of when the trials were initiated. Recruitment to both baits was usually higher at night but not always significantly different from rates observed during the day.

Rates of Recruitment to Liquid and Particulite Oil Baits

Movement of *S. invicta* to the liquid bait was slower than to the particulate bait, and the differences were highly significant ($P \leq 0.01$) (Table 1). The hypothesis of equal recruitment between the two baits was rejected for all but one of the dates studied (Table 2). There are several plausible explanations for observed differences in recruitment to the two baits. A time factor may be involved. Ants had to stay at the vials to drink from the wicks which required more time than transporting an individual bait particle to the nest. Taylor (1978) recognized time spent drinking as an important variable in his model of recruitment rates of *Solenopsis geminata* (F.). The surface area of a food source is another important determinant of recruitment; Wilson (1962) and Taylor (1977) showed that the number of worker ants at a food mass is related to the surface area of the food mass. In our investigation, the particulate bait provided a larger surface area relative to the liquid bait; however, differences in the surface area

TABLE 1. Comparison of the rates of recruitment of *S. invicta* worker ants to particulate and liquid soybean oil baits.

Date	Chi-square[a]	Prob. > chi-square
May 27	15.63	0.008
June 2	24.64	0.0001
June 15	104.18	0.0001
June 28	39.84	0.0001
July 2	32.22	0.0001
Over all dates	97.36	0.0001

[a]Each chi-square value reported is from a 7 X 2 (Time of Day) X (Bait) contingency table and is based on 6 degrees of freedom.

TABLE 2. Comparison of total numbers of *S. invicta* workers recruited to particulate and liquid soybean oil baits.

Date	Particulate bait	Liquid bait	Chi-square[a]	Prob. > chi-square
May 27	280	188	18.08	<0.005
June 2	591	114	269.60	<0.005
June 15	159	143	0.84	>0.10
June 28	315	186	33.22	<0.005
July 2	173	119	9.99	<0.005
Over all dates	1518	750	260.06	<0.005

[a]The chi-squares (df = 1) test the null hypothesis of equal recruitment between the two baits. Significance of chi-square implies unequal recruitment for the two baits.

of the baits does not appear to be an important factor. Workers crowded around individual wicks at the liquid bait, but all of the wicks were never fully occupied by ants. Other factors known to affect recruitment, such as colony size and size-age composition of workers (Sorensen et al. 1981), hunger state (Howard and Tschinkel 1982) and food preferences (Glunn et al. 1981), should have been of no consequence since the two types of soybean oil baits were alternated between the *S. invicta* colonies used. Quality of food could also influence the number of workers recruited to a food source. Hangartner (1969) and Taylor (1977) found *S. geminata* to recruit at greater rates when the concentration of sucrose solutions was increased. Presumably, in our experiment, oil in liquid form would provide a more concentrated, accessible food source (of higher quality) that could be easily spread through the colony through trophallaxis. However, after a more careful examination, the resource values of a worker-load of food (Carroll and Janzen 1973) for the particulate oil bait appear to be greater. We calculate that bait particles contained ca. 30 μg of oil since each particle weighs an average of 0.2 mg and can absorb 15% of its weight in oil (Lofgren et al. 1973). Because only 50% of the oil can be extracted from the particulate bait (Banks et al. 1973), each worker-load of food is equivalent to ca. 15 μg of oil. Sorensen et al. (1981) determined that on the average each *S. invicta* forager ingests 6.57 μg of oil from liquid baits. The two values are sufficiently different to suggest that *S. invicta* may recruit at higher rates to the particulate bait because each particle contains more oil than a worker can consume. Additionally, the storage properties of the two kinds of bait are quite dissimilar. Particulate bait could be easily stored inside the nest and the oil consumed as needed; however, liquid bait would have to be fed immediately to nest mates or retained (in a replete caste). While there is evidence that both of these activities do occur in *S. invicta* colonies, it would seem more likely that *S. invicta* colonies would have a greater capacity in the short term to store particulate bait and for this reason, they recruit to it at higher rates. Certainly more carefully controlled experiments must be carried out to confirm this hypothesis.

Recruitment of Subcastes

Mirenda and Vinson (1981) and Wilson (1978) found that *S. invicta* exhibits a weak polymorphism that is somewhat reflected in task specialization. Small (minor) workers were more likely to care for brood while large (media and major) workers foraged and defended the nest. Wilson (1978) correlated worker size with the size of particles transported. Small workers carried particles of all sizes while larger workers tended to carry only the larger particles. Mirenda and Vinson (1981) showed that media and major foragers were more likely to retrieve solid insect prey than were minor workers. Sorensen and Vinson (1981) reported differences in the size classes or workers recruited to various kinds of food. Smaller numbers of workers of all size classes were recruited to honey, but more media and major workers were found when insects were presented as food. Howard and Tschinkel (1981) found that on an ant-weight basis, foragers of all size classes ingested similar quantities of oil. We found no evidence to suggest that the form in which the oil was presented altered the size of ants recruited. Our analysis of the numbers of ants of each *S. invicta* subcaste recruited indicated that there were no significant differences between the

two baits for the time periods within each sampling date (Table 3). No consistent or biologically rational trend of increase or decrease in the proportion of each subcaste recruited over each 24-hour sampling for each bait was found when the data were examined. While the numbers of each subcaste recruited to the 2 baits on each sampling date were found to vary independently (Table 3), no consistent pattern of difference between the baits was found. We did find that significantly greater numbers of media workers were recruited to the baits relative to minor or major workers. In this regard, our results are consistent with those reported by Mirenda and Vinson (1981). They showed that media workers were more likely to forage relative to minor and major workers.

Impact of Environmental Factors on Recruitment

Attempts to determine the impact of environmental parameters on recruitment yielded models that contained quadratic and interaction forms of the time, temperature and moisture variables measured. Recruitment to the baits did not show a strictly linear relationship with any of these parameters. While air and soil temperatures did have a significant influence on recruitment rates, the proportion of the total variation in recruitment explained by these parameters was small (<25%). Air and soil moisture did not appear to have a significant impact on recruitment to the baits.

Rhoades and Davis (1967) reported that the optimum range of air temperature for *S. invicta* foraging activity is 21°C to 29°C with soil surface temperatures below 35°C. During our investigation, temperatures rarely exceeded these optimum ranges. Air temperature declined below the optimum range found by Rhoades and Davis once during our investigation, but this did not have an adverse effect on recruitment. Because low temperatures generally occurred at night, the observed recruitment patterns could not be attributed solely to temperature. It is possible that high humidity and darkness affected *S. invicta* recruitment activity. Recruitment to oil baits continued throughout the night, usually showing a peak of activity during the dark hours (Fig. 1). Recruitment to the liquid and particulate baits was inhibited more by high temperatures at the end of the 24-hour

TABLE 3. Analysis of the recruitment of *S. invicta* worker subcastes to particulate and liquid soybean oil baits.

Parameter	df[a]	Chi-square[b]	Prob. > chi-square
Intercept	2	4.13	0.127
Bait	2	0.50	0.779
Date	8	14.58	0.0677
Bait X date	8	57.70	0.0001
Bait X time	12	8.93	0.7091
Date X time	48	59.14	0.130
Bait X date X time	44[c]	48.60	0.293

[a]Degrees of freedom for intercept and Bait and Date main effects reflect the fact that separate intercepts have been fitted for each bait.
[b]The total chi-square for bait X date X time was partitioned by the FUNCAT procedure.
[c]Degrees of freedom reflect missing data.

period than at the beginning of the period regardless of when the trials were initiated. This observation suggests that *S. invicta* will recruit to concentrated food sources during unfavorable environmental conditions until the hunger state of the colony is satiated.

ENDNOTES

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A SLAVE-MAKING ANT IN FLORIDA: *POLYERGUS LUCIDUS* WITH OBSERVATIONS ON THE NATURAL HISTORY OF ITS HOST *FORMICA ARCHBOLDI* (HYMENOPTERA: FORMICIDAE)

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ABSTRACT

The slave-making ant *Polyergus lucidus* is reported for the 1st time from Florida. *Formica archboldi* is its host species, not previously known to be parasitized in this way. The behavior of these 2 species is described and compared to that of related forms from other regions.

RESUMEN

Se registra por primera vez la hormiga esclavista *Polyergus lucidus* de la Florida. *Formica archboldi* es su hospedero, que no se conocía previamente que era parasitado de esta forma. Se describe el comportamiento de las 2 especies, y se compara con el de hormigas emparentadas de otras regiones.

Dulosis is a form of social parasitism in which the workers of 1 species of ant periodically raid colonies of related species for brood. The plundered brood is reared in the nest of the parasite by workers of the host species which serve as the nurse, forager, defense, and construction force for the mixed colony. Often referred to as slave-making, this type of parasitism is unique to Formicidae, but has arisen several times independently within the family (Wilson 1971).

Talbot (1967, 1968), Harman (1968) and Marlin (1968, 1969, 1971) have reported on the natural history of *Polyergus lucidus* Mayr in Michigan and Illinois, and Kwait and Topoff (1983) have recently published on the species'