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Research Article

Predation of Fruit Fly Larvae *Anastrepha* (Diptera: Tephritidae) by Ants in Grove

W. D. Fernandes,[1] M. V. Sant'Ana,[1] J. Raizer,[1] and D. Lange[2]

[1] *Faculdade de Ciências Biológicas e Ambientais, Universidade Federal da Grande Dourados (UFGD), MS 162, Km 12, 79804-970 Dourados, MS, Brazil*
[2] *Laboratório de Ecologia Comportamental e de Interações, Universidade Federal de Uberlândia (UFU), P.O. Box 593, 38400-902 Uberlândia, MG, Brazil*

Correspondence should be addressed to W. D. Fernandes, wedson@ufgd.edu.br

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Based on evidence that ants are population regulatory agents, we examined their efficiency in predation of fruit fly larvae *Anastrepha* Schiner, 1868 (Diptera: Tephritidae). Hence, we considered the differences among species of fruit trees, the degree of soil compaction, and the content of soil moisture as variables that would explain predation by ants because these variables affect burying time of larvae. We carried out the experiment in an orchard containing various fruit bearing trees, of which the guava (*Psidium guajava* Linn.), jaboticaba (*Myrciaria jaboticaba* (Vell.) Berg.), and mango trees (*Mangifera indica* Linn.) were chosen for observations of *Anastrepha*. We offered live *Anastrepha* larvae on soil beneath the tree crowns. We observed for 10 min whether ants removed the larvae or the larvae buried themselves. Eight ant species were responsible for removing 1/4 of the larvae offered. The *Pheidole* Westwood, 1839 ants were the most efficient genus, removing 93% of the larvae. In compacted and dry soils, the rate of predation by ants was greater. Therefore, this study showed that ants, along with specific soil characteristics, may be important regulators of fruit fly populations and contribute to natural pest control in orchards.

1. Introduction

The fruit fly *Anastrepha* spp., together with some rarer *Rhagoletis* Loew, 1862, and *Ceratitis capitata* (Wiedeman, 1824) (Tephritidae), cause damage to fruit crops in Brazil. Tephritids directly damage the fruit, because the orifice made to lay the eggs causes the fruit to rot and fall prematurely, and the larvae feeding destroy the fruit pulp [1]. Ants, a group of efficient insect predators that regulate populations of general insects [2–8], can be considered as agents of biological pest control in agroecosystems [9–11]. The predation by ants on fruit flies occurs when the larvae leave the fruit in order to bury themselves in the soil and transform into pupae. *Solenopsis geminata* (Fabricius, 1804) ants, for example, were responsible for predation of 95% of the *Anastrepha ludens* (Loew, 1873) larvae during the warm months in Mexico [7]. In Guatemala, these ants attacked 21.6% of the *C. capitata* larvae in orange groves and 9.3% in coffee plantations [8].

Predation is strongly and indirectly influenced by the physical properties of the soil, because the larvae took longer in burying themselves in very dry soil, increasing the time in which they remained exposed and consequently the rate of ant predation [12]. In this study, we analyzed which factors were present and how they influenced the predation of fruit flies by ants, considering the different species of fruit trees, and the degree of soil compaction and moisture content.

2. Material and Methods

We conducted the experiment in a grove of the Universidade Federal da Grande Dourados (UFGD) (Mato Grosso do Sul state, Brazil, 22°13′16′′S and 54°48′20′′W), on the 8th, 10th, 11th, 14th, 18th and 21st of February 2007. The local

Table 1: Number and total percentage of larvae removed by ants beneath the crowns of 60 trees of three species of fruit, in a grove of the Universidade Federal da Grande Dourados, during an experiment offering groups of three larvae under each crown. Guava is *Psidium guajava*, jaboticaba *Myrciaria jaboticaba*, and mango *Mangifera indica*.

Subfamilies	Species or morphospecies	Fruit trees			Total (%)
		Guava (30 trees and 90 larvae)	Jaboticaba (11 and 33)	Mango (19 and 57)	
Myrmicinae	*Pheidole oxyops* Forel, 1908	7	6	16	67.44
	Pheidole gertrude Forel, 1886	4	—	—	9.30
	Pheidole sp. 1	2	2	—	9.30
	Pheidole sp. 2	1	1	—	4.65
	Pheidole sp. 3	1	—	—	2.32
Dolichoderinae	*Dorymyrmex* sp. 1	—	—	1	2.32
Ponerinae	*Odontomachus chelifer* (Latreille, 1802)	1	—	—	2.32
Ectatomminae	*Ectatomma brunneum* Smith F., 1858	—	—	1	2.32
Total		16	9	18	100

soil is red latosol eutrophic alic [13], and the climate is subtropical humid [14]. In the grove of 4 ha, there are various fruit trees, such as *Psidium guajava* Linn. (Myrtaceae) (popular name guava), *Myrciaria jaboticaba* (Vell.) Berg. (Myrtaceae) (popular name jaboticaba), *Mangifera indica* Linn. (Anacardiaceae) (popular name mango), which we used in this experiment, as well as all fruit trees of grove are arranged in blocks according to species, and only the guava trees had fruit at the time of the experiment. Sixty fruit trees were randomly chosen for the experiment: 30 guavas, 11 jaboticabas, and 19 mangoes. This number is referent to 50% of total individuals of these species of grove.

Beneath the trees' canopies, we delimited an area of 1 m^2 (quadrant) and we removed all vegetal biomass one day before the experimentation to facilitate observation and capture of ants. In each quadrant, we offered simultaneously three last instar larvae *Anastrepha* ssp., obtained from infested guava fruits in the same area of study. We released larvae individually from a height of ~30 cm above the ground, simulating the larva falling from a fruit. During 10 min, from the moment at which the larvae reached the ground, we recorded the time in which the larvae buried themselves, if the larva was attacked and removed by ants (larvae removed), and the time taken by ants to remove them (removal time). All experiments were done at the same period of the day (between 7:00 and 11:00 am), corresponding to the period of the highest incidence of larvae leaving the fruit. Our sampling unit consisted in each larva offered.

After the observations, we collected all ants active in removal of larvae and identified the species according to the dichotomous key of Bolton [15]. Then we stored the ant species in the Laboratório de Mirmecologia of UFGD.

To determine the degree of soil compaction, we used the measure of soil density. We collected 60 soil samples under the canopy of tree after each day of observation. The samples were oven-dried at 110°C for three days. Samples were collected using a metallic cylinder of 4.2 cm in diameter and 5 cm in height. We obtained soil density dividing the dry weight of soil (after 3 days) by the volume of the sample. To determine the soil moisture, we weighed the samples before and after three days in the dryer. The ratio between the initial and final weight multiplied by 100 corresponds to the percentage of moisture. During the days of field study, we recorded the weather conditions, such as daily temperature, relative moisture, and wind speed.

We performed the analysis of covariance (ANCOVA) to verify whether the removal time was dependent on the species of trees, the number of larvae removed, and the interaction between these variables. We used a multivariate analysis of variance (MANOVA) to test the difference in soil compaction and moisture in tree species. We also used models of multiple regression to evaluate if the average time to bury and rate of predation were related to soil moisture, soil compaction, or the interaction between these two variables.

The interaction between the soil characteristics and the species of fruit trees was considered as independent variables. We used multiple regression test to verify whether the time of larvae spent in burying themselves was related to soil moisture and compaction. For this test, we used 30 samples in which the larvae were not predated by ants.

3. Results

From 180 fly larvae used in the experiment, 43 (24%) were removed by ants, 88 (49%) buried themselves, and 49 (27%) did not bury themselves and were not removed by ants. Eight ant species in four genuses and four subfamilies were recorded removing larvae. *Pheidole* (Myrmicinae) accounted for 93% of predation upon larvae (40 records of removal), and individuals of *Pheidole oxyops* Forel, 1908 were the most efficient, removing 67.44% of the larvae (Table 1).

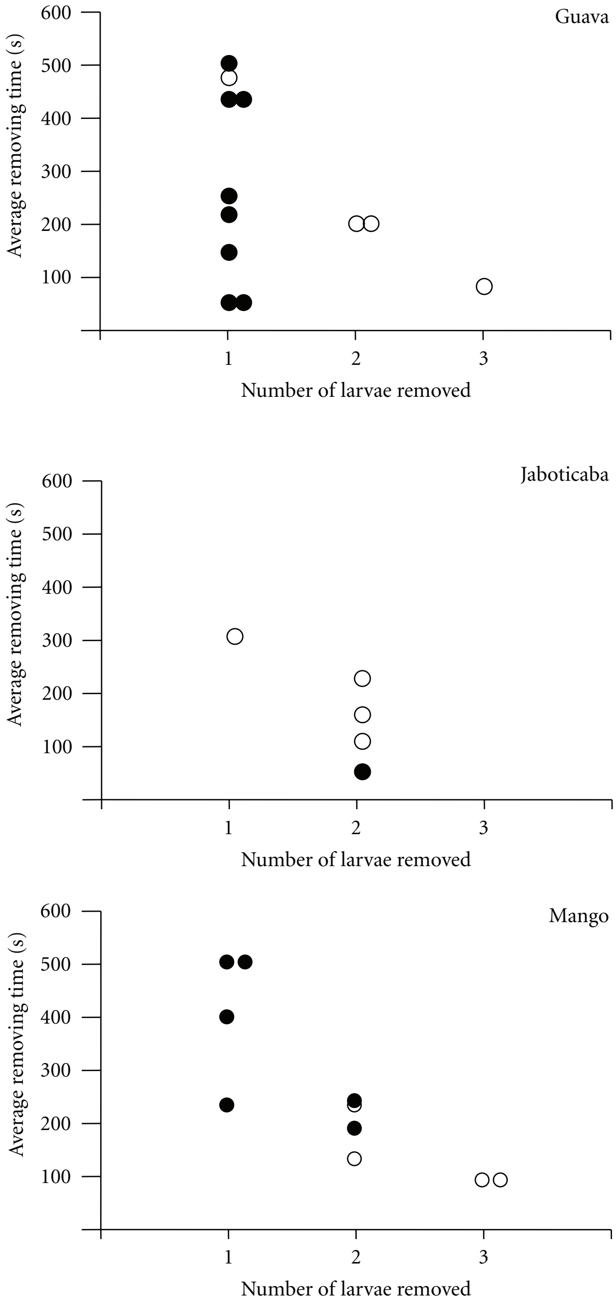

Figure 1: Relationship between amounts of fruit fly larvae (Tephritidae) removed by ants and average time for removal of each larva beneath the crowns of three species of fruit trees. Empty points are samples without larvae burying themselves. Guava is *Psidium guajava*, jaboticaba *Myrciaria jaboticaba*, and mango *Mangifera indica*.

The ants removed 16 of these larvae under the canopy of guava trees (all bearing fruit), nine under jaboticabas, and 18 under mangoes. The average time for the larvae to bury themselves was only obtained from 45 samples (26 guavas, six jaboticabas, and 13 mangos), because the larvae in 15 samples did not show this behavior. In 33 samples, there was no attack by ants and the mean of removal time was obtained only from 27 samples (12 guavas, five jaboticabas, and 10 mangos).

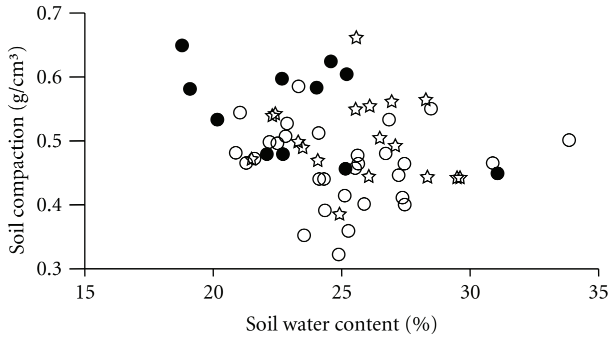

Figure 2: Soil moisture and compaction beneath of crowns the fruit trees. Open circles: guava (*Psidium guajava*); filled circles: jaboticaba (*Myrciaria jaboticaba*); stars: mango (*Mangifera indica*).

The mean time required to remove a larva decreases as the number of larvae attacked and removed increased ($F = 7.356$; $P = 0.013$; gl = 1; Figure 1). This significant effect is more evident among samples in which the larvae did not bury themselves (open circles in Figure 1). Moreover, ANCOVA results showed that the removal time was independent of the tree species ($F = 0.894$; $P = 0.424$; gl = 2) and the interaction between number of larvae removed and tree species ($F = 0.449$; $P = 0.644$; gl = 2). The presence of fruit only in guava did not affect the removal time of the larvae.

Climatic data showed that weather conditions were constant throughout the study. The average daily temperature ranged between 23.7 and 25.5°C, relative moisture varied between 72.4 and 89.6%, and wind speed between 0.8 and 1.6 ms-1. It rained only on the nights of 7th (29.5 mm), 12th (0.3 mm), and 16th (14.2 mm).

The predation rate of larvae was affected by the different soil characteristics, as the larvae take longer to bury themselves in dry soil. Soil compaction and moisture were dependent on tree species (MANOVA: Pillai trace value = 1.195, $P < 0.001$, df = 6 and 112, Figure 2), being that the soil under the jaboticaba canopy had the highest compaction and lower moisture. The average time for burying itself under the different species of fruit trees was significantly related to the soil moisture ($F = 3.803$; $P = 0.037$; gl = 2; Figure 3), but not related to soil compaction ($F = 1.052$; $P = 0.366$; gl = 2), nor to the interaction between these two variables ($F = 0.553$; $P = 0.582$; gl = 2).

Soil characteristics affected the rate of larvae predation by ants (Figure 4). In soils with higher moisture, the predation was lower ($F = 4.753$, $P = 0.021$, df = 2), and in more compacted soil, the rate of predation was greater ($F = 5.989$, $P = 0.010$, df = 2). Interaction between these two independent variables also explained the predation rate ($F = 6.163$, $P = 0.009$, df = 2). In other words, ants were more efficient in preying on larvae on drier and more compact soil, despite compaction having no effect on the larvae burying time (Figure 5).

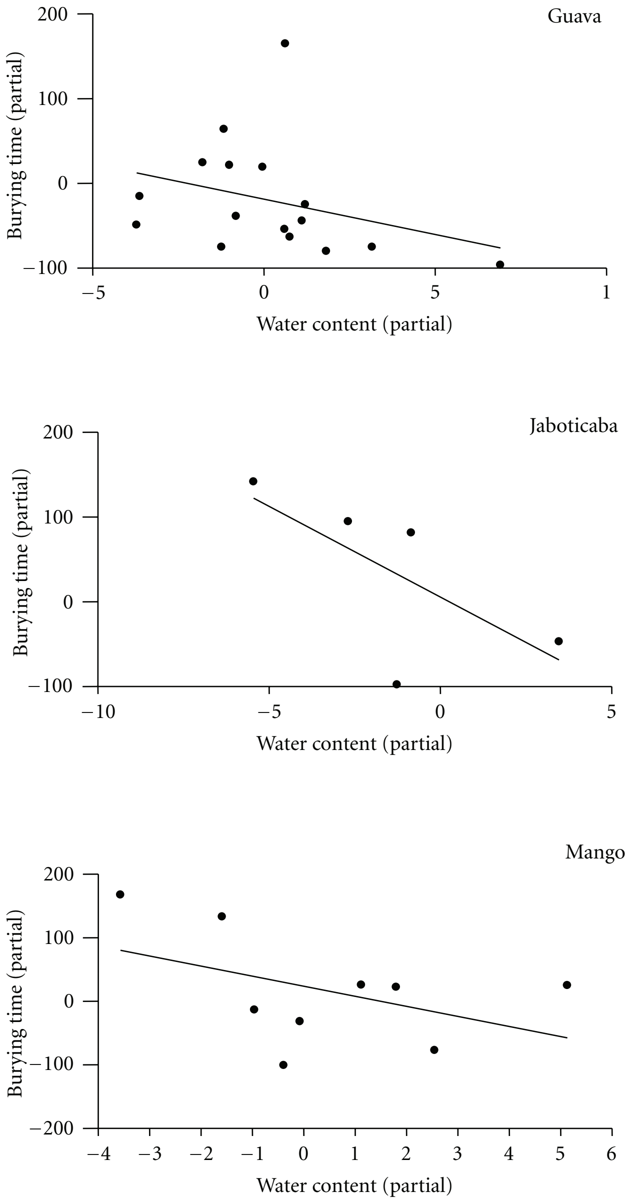

Figure 3: Average time until fruit fly larvae bury themselves through gradient of water content of soil beneath the crowns of three species of fruit trees. Only larvae that were not predated by ants were included. Partial residuals were obtained from a multiple-linear model that included compaction of soil (no significant effect). Guava is *Psidium guajava*, jaboticaba *Myrciaria jaboticaba*, and mango *Mangifera indica*.

4. Discussion

We observed that ants removed approximately 1/4 of the fruit fly larvae released on soil. This value is similar for biological control levels [3, 16, 17] and high for predation of the fruit flies by ants in most studies [8, 12]. Among the predatory ants genus, *Pheidole* individuals were more efficient, accounting for 93% of the larvae removed. The predominance of attacks by these ants evidenced their role as efficient predator, which is also due to their wide distribution, high species richness, and good adaptation to the physical conditions of the environment [18]. Its aggressive behavior and efficient and massive recruitment increment this efficiency [19]. The potential performance of *Pheidole* as agents of biological pest control was also demonstrated in the fight against *Anthonomus grandis* Boheman, 1843 (Coleoptera: Curculionidae) in cotton fields in Brazil [10].

Strategies for predation and defense of organisms are among the most discussed topics in ecology and evolution [20, 21]. These relationships determine the survival or extinction of populations and the structure and maintenance of communities. Thus, if in the case of fruit flies, the rapid penetration into the soil is the best strategy to prevent their predation [7, 12], then the soil characteristics as well as the

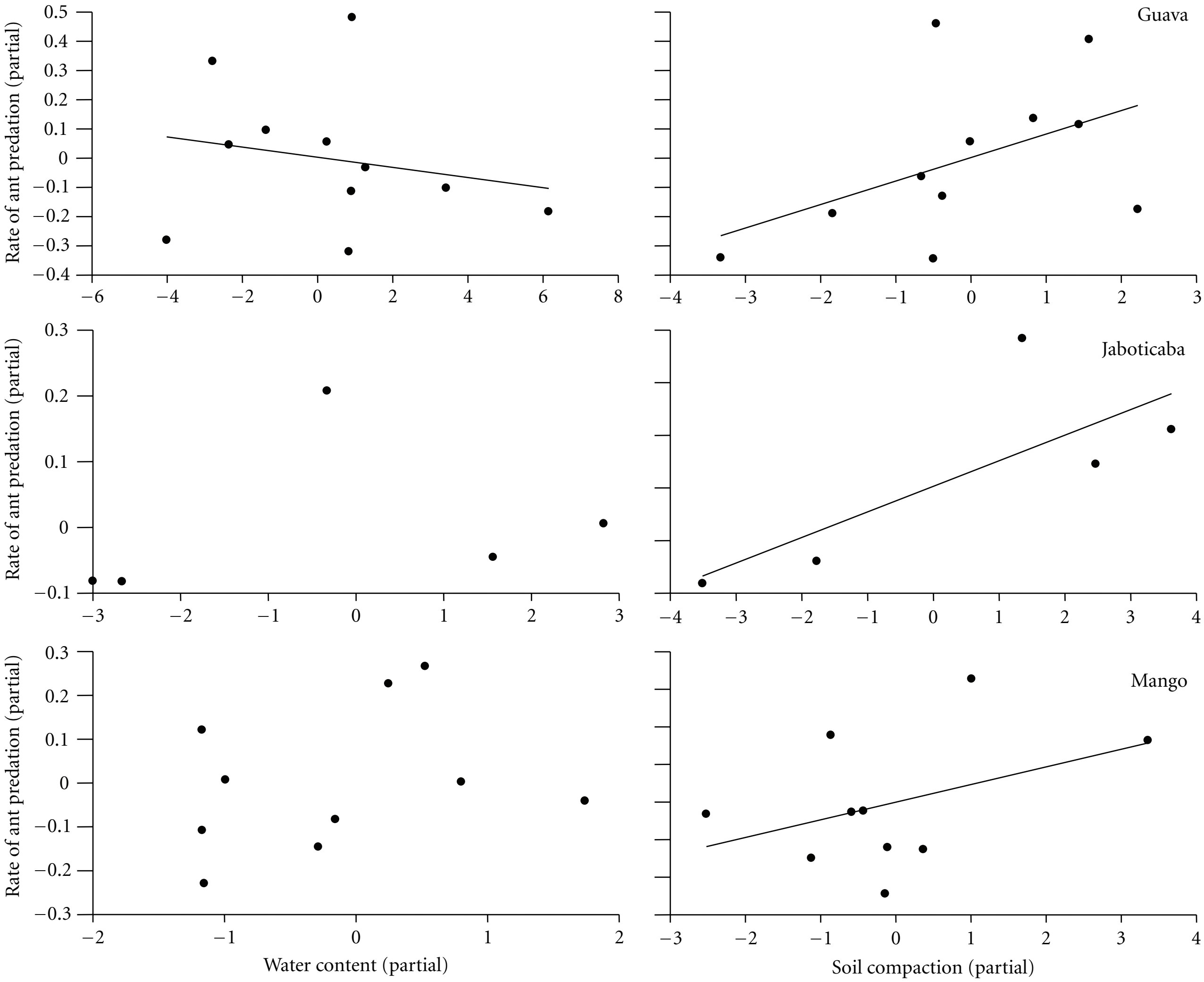

Figure 4: Ant predation on fruit fly larvae through gradients of water content and compaction of soil beneath the crowns of fruit trees of three species. Partial residuals obtained from multiple-linear model. Guava is *Psidium guajava*, jaboticaba *Myrciaria jaboticaba*, and mango *Mangifera indica*.

larvae ability of bury themselves are determinants for their survival. However, in this study, we found that larvae which were dropped on compacted and uncompacted soil took the same time to penetrate the soil. Although the time to drill the soil by larvae was not directly related to compaction, it was significantly associated with soil moisture, another determinant factor for the success of the burying behavior [22, 23] and for the development of pupae [24]. The lack of moisture in the soil can cause mortality of a large number of larvae, because the soils become more difficult to be bored [22]. Wet soils have greater tension between the particles resulting in larger particles and larger spaces among them [25]. Thus, wet soils are more easily bored by fruit fly larvae, as evidenced in this study.

Here we have evidence that both soil tilling and tree species influence the efficiency of ants in attacking the larvae. Several studies have shown that the abundance, not only of ants, but of other predators such as carabid beetles and spiders, increases with farming practices that reduce soil turnover [26, 27]. This fact should be related to environment complexity and colony stability. Tillage systems in which the soil is not turned have a higher plant biomass on the soil surface [28], and this increases the availability of nutrients and shelter for many organisms. Thus, these communities have more local biodiversity [29, 30]. In addition, soil disturbance could have caused the death of various ant colonies, decreasing the number of individuals foraging for resources. Moreover, the tree species may also have influenced the soil characteristics through their complex canopy structure and root density.

Here we showed that rate of ant predation on fruit fly larvae was affected by soil, because larvae took longer to bury themselves in dry and compacted soil. Therefore, the moisture and compaction level of soil, resulting from the type of tillage and tree species, has a profound influence on the burying of larvae influencing the efficiency of ant predation (Figure 5). Nevertheless, the presence of fruit was not a determinant factor in the predation of larvae among the

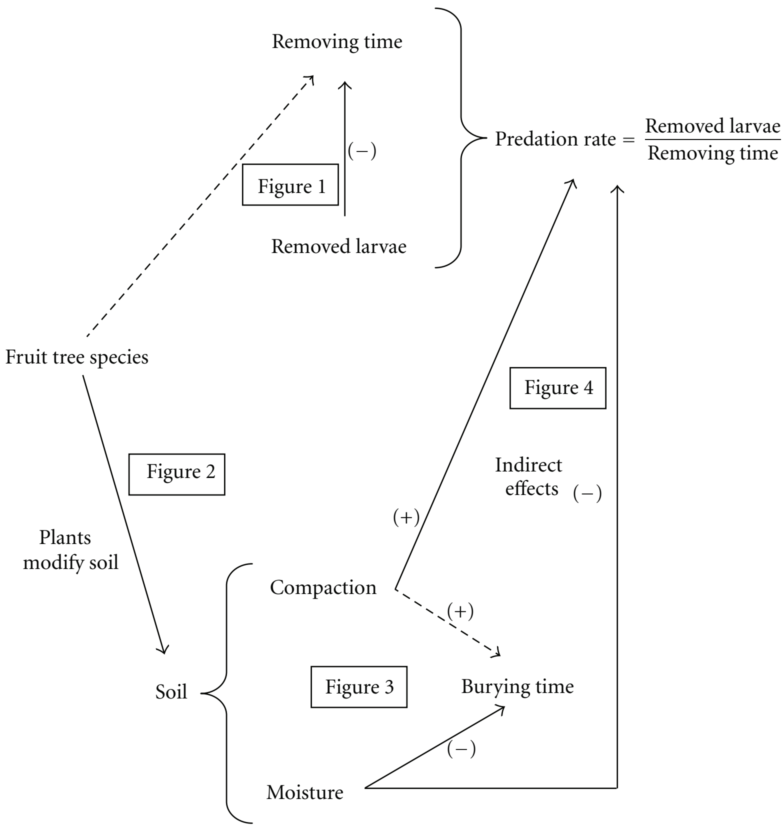

Figure 5: Effects' diagram for predation of fruit fly larvae by ants. Evidences for effects are in the indicated figures. Dashed lines: no statistical evidence; (+): positive effect; (−): negative effect.

fruit trees. This result was also evidenced by Aluja et al. [12]. Although we would expect that ants were more abundant in locations with higher density of fruit, for example, [31], due to the greater number of larvae, only guava trees were bearing fruits at the time of study, which could have masked the effect of fruit.

In this study, we showed that ants, mainly of *Pheidole* genus, are important predators of *Anastrepha* larvae, and can contribute to regulate this crop pest population. Furthermore, we also evidenced that the rate of ant predation depends on soil characteristics and fruit tree species. Thus, ants may have a beneficial impact on fruit growing and, together with other control methods, can reduce cost with insecticides and act as an important tool in integrated pest management.

Acknowledgments

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