Microclimates and their Stochastic Effect on Olive Fruit Fly Evolution: Modeling and Simulation

Romanos Kalamatianos[1], Markos Avlonitis[2]

Department of Informatics, Ionian University, Greece, e-mail: {[1]c14kala, [2]avlon}@ionio.gr

Abstract. Climate variables play an important role in the development and general activity (diffusion, oviposition etc.) of the olive fruit fly. These variables can fluctuate from area to area due to the topography of the area and several other factors. Due to this fluctuations microclimates are created. Through simulation runs we investigate how the population dynamics of the olive fruit fly are affected in four distinct microclimates, from an olive grove area in Corfu, Greece with environmental data collected from environmental sensors. Finally, we investigate how current spraying practices affect the population of the olive fruit fly in each microclimate.

Keywords: olive fruit fly, microclimate, simulation model

1 Introduction

Bactrocera oleae also known as olive fruit fly is a widespread pest of olive trees in many Mediterranean countries, such as Greece, as well as other olive producing countries around the world. Olive fruits are the growth habitat of all three premature stages of the insect. Female olive fruit flies oviposit the eggs inside the fruit and the larva that hatches feeds from it. At the last premature stage the insect pupates either inside the fruit or in the ground until the perfect adult emerges (Vossen et al, 2004). The total number of olive fruit fly generations per year varies from region to region due to changes in the climate. Up to five generations were reported in Southern California, with the authors stating that under ideal conditions the olive fruit fly could reach seven generations (Rice et al, 2003). While, in Jordan up to three generations have been documented (Mustafa and Alzaghal, 1987).

The development and activity of the olive fruit fly is heavily dependent upon environmental conditions. Both temperature and relative humidity are important enviromental factors that affect the population dynamics of the olive fruit fly. Specifically, the development rate of the immature stages increases as the environmental temperature increases within the developmental thresholds (Tsitsipis 1977 & 1980). When exposed to high temperatures, even for a couple of hours, it affects all development stages in terms of longevity, reproduction and survival (Pappas et al, 2010). Furthermore, high temperatures affect the flight performance of adult olive fruit flies (Xin-Geng Wang et al, 2009). Likewise, low values of relative

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humidity, below 33%, reduces ovarian maturation of female olive fruit flies, as well as the longevity of the adult flies. For higher values percentages of the aforementioned parameters increase (Broufas et al, 2009).

Both aforementioned environmental parameters are affected by the topography of a region. For instance temperature is known to decrease with increasing altitude, also known as the lapse rate, which ranges from 5.5^{o}C, to 6.5^{o}C, per 1000m gain in altitude (Hodkinson, 2005). Temporal and spatial variations of solar radiation, cloud coverage, the presence of shading and proximity to the sea, or to mountains, among others, can also have an impact on environmental conditions. All these factors constitute in the creation of a microclimate. Thus, an olive grove field depending on the topography of its location and size can exist in the same microclimate, or it can be divided into numerous microclimates.

The population size of the olive fruit fly inside an olive grove if left unchecked can reach high numbers, infesting the whole grove as a result. Therefore, several methods are used to monitor and control the population, which can be divided into two main categories (Vossen and Devarenne, 2006).

The first category is mass trapping, where some type of trap is placed on every tree inside the grove. Types of traps include the Attract and Kill device, which is a cardboard, coated with pesticide killing olive fruit flies coming in contact with it. Other types of traps are the McPhail trap, which is a liquid trap that baits olive fruit flies and the Sticky panel trap which is a yellow cardboard with a non-drying sticky coating that lures olive fruit flies. Finally the OLIPE trap which is a plastic bottle with small holes, filled with the same liquid solution as the McPhail trap.

The second category of population control is spraying. One method of spraying is the Kaolin clay, which creates a fruit barrier preventing olive fruit flies from laying eggs inside it. Another method of spraying is the Spinosad bait, which is sprayed onto every other tree and lures olive fruit flies to feed from it and eventually die.

Aim of this paper is to investigate, via simulation runs, how the evolution of the olive fruit fly is affected by the microclimate it resides in. As well as, the effect current patterns of spraying have on the population of the olive fruit fly when the existence of microclimates is disregarded. In an earlier version of the simulation model (Voulgaris et al, 2013) a comparison of the spatial distribution of the olive fruit fly of a good spraying scenario versus a bad spraying scenario was presented.

2 Material and Methods

2.1 Simulation Model

In order for the simulation to be executed, information about the field must be given as input. Therefore, different layers of information are passed, the first layer provides the location of olive trees and urban areas, as well as the location of olive fruit fly traps (Voulgaris et al, 2013). The second layer provides the percentage of olive fruit that is present at the olive grove locations (Kalamatianos & Avlonitis, 2015). Finally, we upgraded the model to identify one or more microclimates that the field is divided to and attach to each a different temperature set. All areas inside a microclimate have the same temperature. Given the aforementioned information the simulation model creates a grid representing the real life field and populates its cells with a starting population based on olive fruit fly trap measurements.

The population is structured into five transformation stages. Namely, egg, larva, pupa, sexually immature adult and fully mature adult. All adults are considered female olive fruit flies and each of them can lay up to three eggs in its lifetime.

The degree-day model (Wilson & Barnett, 1983) is utilized to simulate the development of the pre-imaginal stages (egg, larva, pupa) of the olive fruit fly. Since, the time resolution is hourly the following equation is used to compute the accumulated degree hour units (Kalamatianos & Avlonitis, 2015).

$$DH(t_i) = ((t_i - T_L) * (1 - (1 / (1 + \exp(-10 * (t_i - T_U)))))) / 24. \quad (\mathbf{1})$$

Where t_i is the temperature present in the i-th simulation step, T_L and T_U are the lower and upper developmental thresholds, respectively, of each olive fruit fly which differs from one transformation stage to the other.

For the spatial dispersion of the olive fruit fly the first major parameter is olive fruit percentage. The average speed of an olive fruit fly based on the olive fruit percentage of its current position is calculated using Equation 2 (Kalamatianos & Avlonitis, 2017).

$$AvgSpeed(f_{x,y}) = (-4.513 * f_{x,y} + 451.8) / wh. \quad (\mathbf{2})$$

Where $f_{x,y}$ is the olive fruit percentage on (x, y) coordinates of the grid and when the total daytime hours in the current week. The second parameter is temperature, which affects the final speed of the olive fruit fly. Equation 3 calculates the speed of the olive fruit fly based on the temperature present at its current position

Fig. 1. Map of the study area in Corfu, Greece. (Map data: Google, TerraMetrics, Data SIO, NOAA, U.S. Navy, NGA, GEBCO, CNES/Airbus)

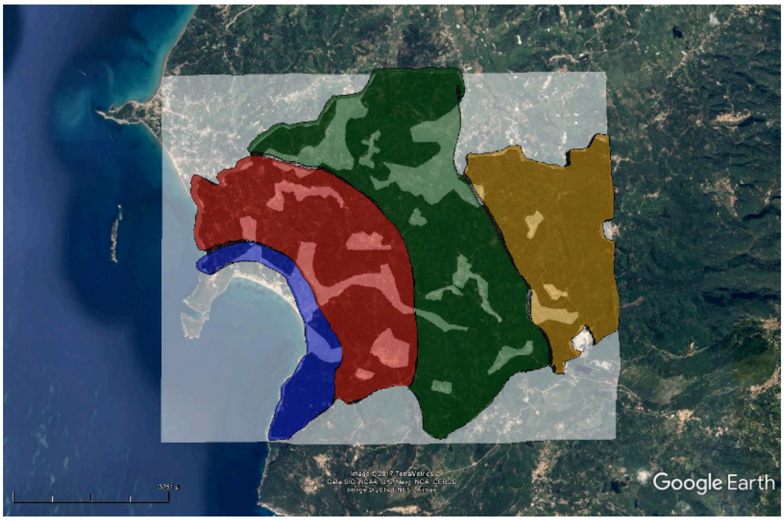

Fig. 2. Study area microclimate division. Blue colored is microclimate A, red colored is microclimate B, green colored is microclimate C and yellow colored is microclimate D. (Map data: Google, TerraMetrics, Data SIO, NOAA, U.S. Navy, NGA, GEBCO, CNES/Airbus)

(Kalamatianos et al., 2015).

$$Speed(f_{x,y},t_i) = AvgSpeed(f_{x,y}) * (1 - (1 / (1 + exp(-10 * (t_i - T_U))))). \qquad \textbf{(3)}$$

Where t_i is the temperature present in the i-th simulation step, T_U is the upper movement threshold. The upper movement threshold was set to 35 ^oC, beyond this temperature the olive fruit flies stop drifting (Avidov, 1954; Johnson et al., 2011).

2.2 Study Area

The study area was the municipality of St. George (Figure 1), which is located on the northwestern part of the island of Corfu, Greece. High temperatures and almost no rainfall in general characterize the climate type of the study area and the island during the summer months. The total area is 9km x 7,5km.

Although the study area may consist of many microclimates, the data we collected wasn't enough to distinguish the different microclimates. Thus, for simplicity reasons we divided the area arbitrarily into four microclimates as they are depicted in Figure 2. The resulting microclimates from left to right are designated as microclimate A, B, C and D.

2.3 Data

Figure 3 depicts the locations where environmental sensors were installed. Microclimates where more than one sensor was installed, the average value was calculated from all sensors and was used to represent the temperature for all areas

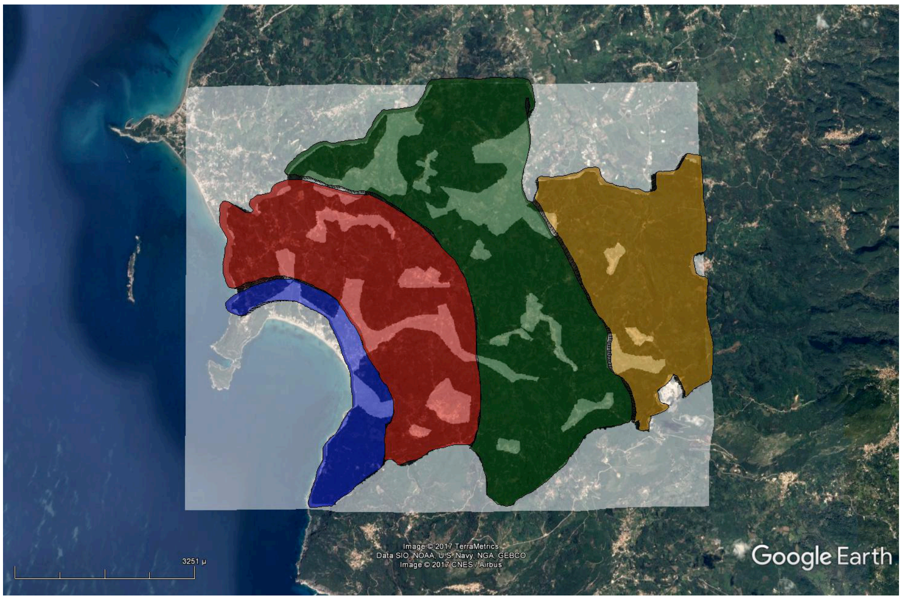

Fig. 3. Environmental sensors. (Map data: Google, TerraMetrics, Data SIO, NOAA, U.S. Navy, NGA, GEBCO, CNES/Airbus).

inside the microclimate. For microclimate C, where no environmental sensor was installed, we calculated the average value from both neighbouring microclimates, namely microclimates B and D.

The installed environmental sensors recorded temperatures from 19th June 2015 until 9th November 2015 at a 15-minute interval. We choose to use the recorded temperatures for the time period from 21st June 2015 to 20th October 2015 for our

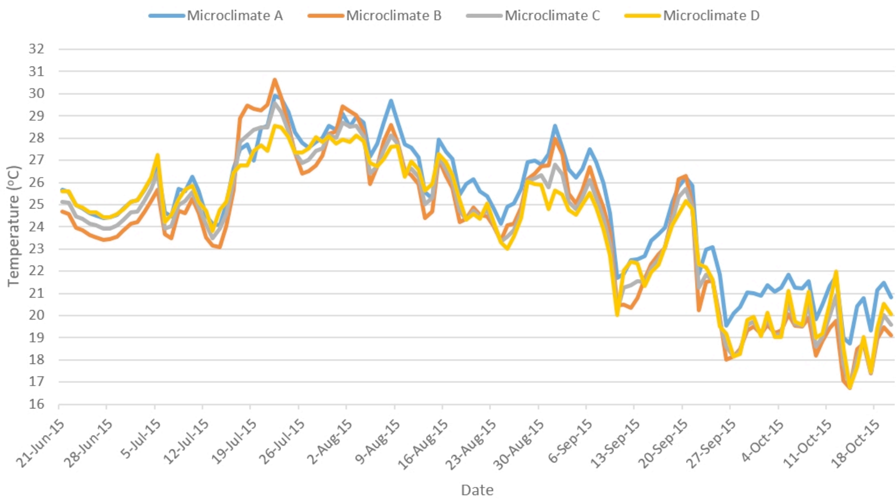

Fig. 4. Average daily temperatures for each microclimate.

experiments. Figure 4 depicts the average daily temperatures of each microclimate for the selected time period.

Microclimate A seems to have a warmer climate, as well as microclimate B which seems to be a bit cooler than the aforementioned microclimate. On the other hand, microclimate D has a colder climate than the rest microclimates. While microclimate C is between microclimate B and D since the temperatures provided are a combination of the aforementioned microclimates.

2.4 Simulation Scenarios

For both of the following simulation scenarios the simulated field was the former municipality of St. George (Figure 1) which was divided into four microclimates (Figure 2). The temperature sets for each microclimate was for the time period from 21st June 2015 to 20th October 2015 and the fruit bearing percentage was set to 75% for all olive grove areas inside the simulated filed. We run the following two simulation scenarios, in the first scenario we let the olive fruit flies to develop without any interference i.e. spraying, in order to observe the temporal evolution of the population of the olive fruit fly. In the second scenario, a single spray is conducted, with a mortality rate of 75%, on the 20th July, which is generally the time when local agricultural authorities commence the first universal spray. Generally, local authorities conduct three sprays in total. The first spray is conducted between 10th to 20th July, the second is conducted between 10th to 15th August and finally the last spray is conducted during the last days of September up until 10th October. The first spray is always a universal spray while the two latter are local sprays, meaning only specific areas are treated.

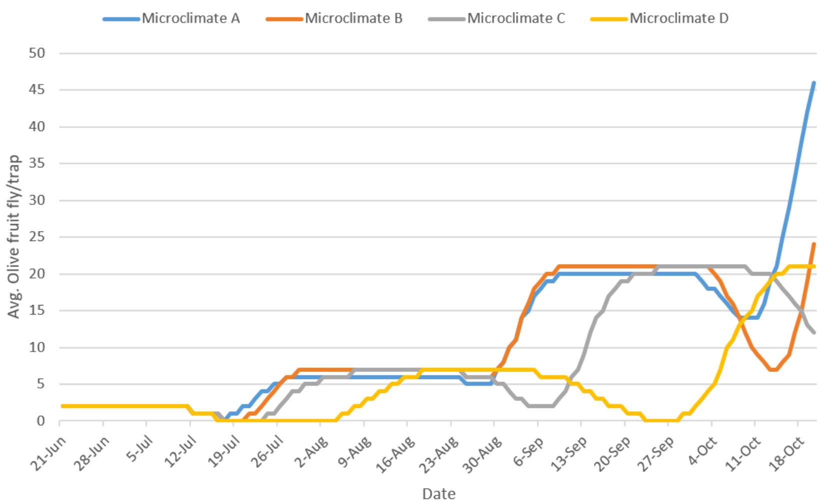

Fig. 5. Olive fruit fly evolution in each microclimate without spraying.

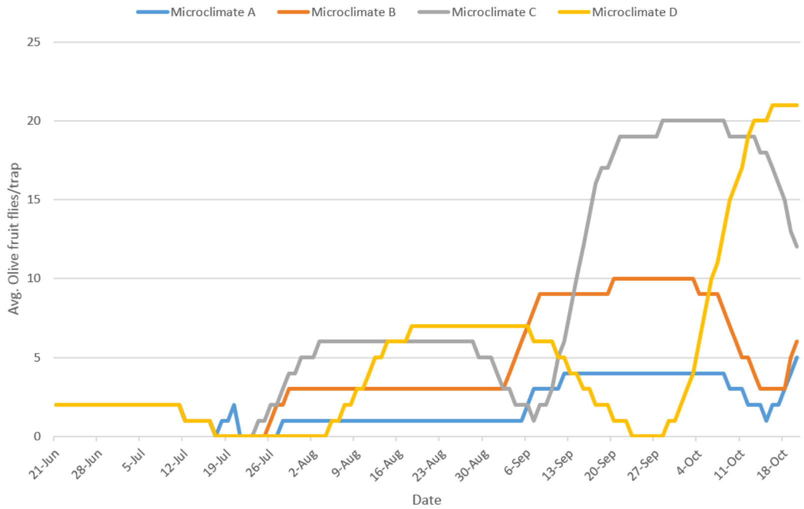

Fig. 6. Olive fruit fly evolution in each microclimate after single spray.

3 Results

Figure 5 displays the evolution of the population of the olive fruit fly for each microclimate without conducting any spray during the simulated time. It is obvious that the temperature set of each microclimate has an effect upon the population dynamics of the olive fruit fly. For microclimate A and B two generations are visible

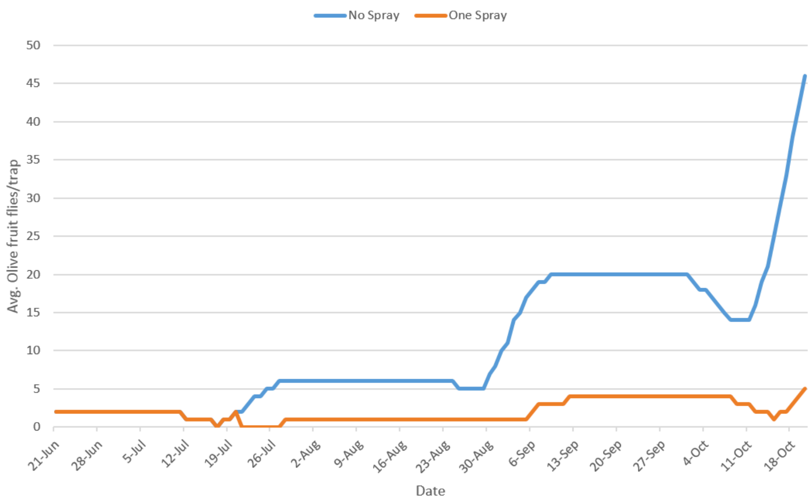

Fig. 7. Population evolution comparison for Microclimate A before and after spray.

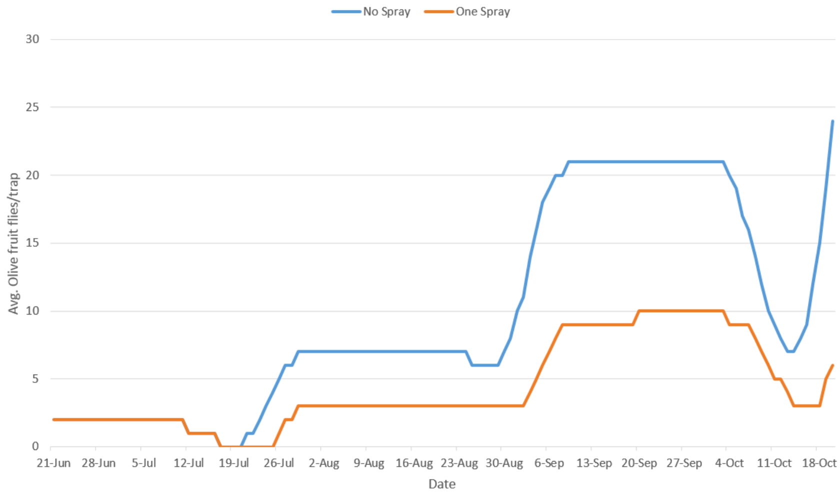

Fig. 8. Population evolution comparison for Microclimate B before and after spray.

and the 3rd generation starts to emerge at the end of the simulated period. On the other hand, for microclimate C and D only two generations are visible. In addition, there seems to be a delay to the development and emergence of the first generation, and consequently for each following one, between each microclimate. The smallest delay is seen between the neighboring microclimates A and B of four days while the biggest delay is observed between microclimates A and D with a delay of the latter of 19 days.

The effect of a single spray one month after the start of the simulation, namely at 20th July, is depicted in Figure 6. The population dynamics of the olive fruit fly in the areas corresponding to microclimates A and B are greatly affected. However, that's not the case for the population in microclimates C and D which seem to be unaffected by the conducted spray.

The following figures compare the population evolution of the olive fruit fly before and after spraying for each microclimate. In Figure 7, a comparison for microclimate A can be seen. It is obvious that the spray had a devastating effect upon the evolution of the olive fruit fly. It is important to note that, the population size until the end of the simulation was below the infestation threshold.

The comparison for microclimate B is depicted in Figure 8. The spray that was conducted seems to have greatly affected the evolution of the olive fruit fly. Although, the effect is not as devastating as is the case for microclimate A, the population size of each subsequent generation has greatly decreased. The population size for the first generation is below the infestation threshold and for the second generation the population size is almost halved when compared to the population evolution of the first simulation scenario.

On the other hand, microclimate C (Figure 9) is slightly affected by the conducted spraying. Since, there is only a minor decrease in the size of the population between the two simulation scenarios.

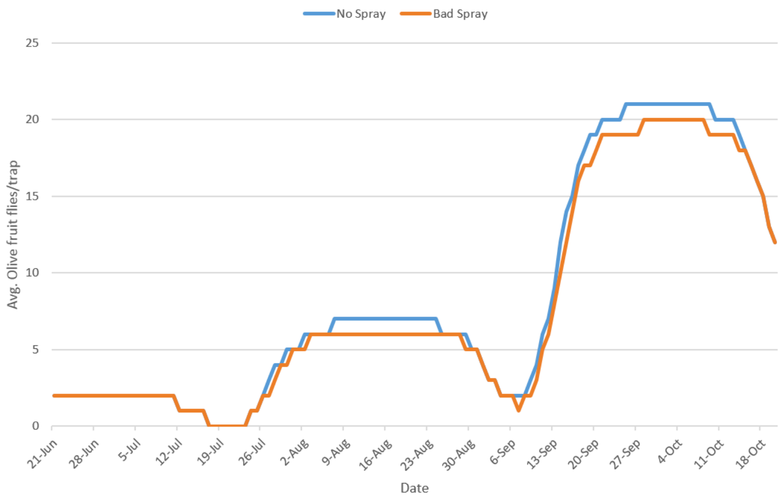

Fig. 9. Population evolution comparison for Microclimate C before and after spray.

Finally, areas belonging to microclimate D seem to be impervious to the spraying conducted in the second simulation scenario (Figure 10), as if the spraying had never happened.

4 Conclusions

The effect of microclimates on the population evolution of the olive fruit fly is investigated. Therefore, we modified our simulation model to be able to divide the

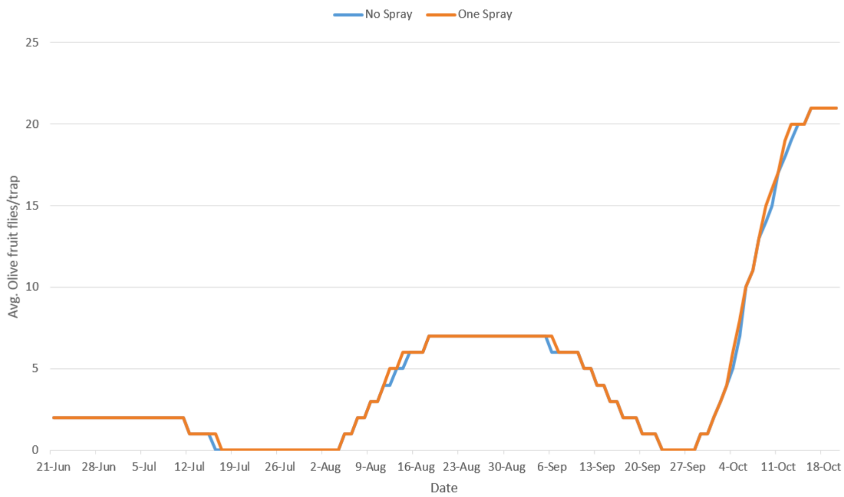

Fig. 10. Population evolution comparison for Microclimate D before and after spray.

simulated field into one or more microclimates as specified by the user, where each microclimate has its own distinct temperature set. The study area was the former municipality of St. George, Corfu, Greece, which we divided into four microclimates while the temperature sets for each microclimate were provided from environmental sensors installed in the area.

The results of the simulation scenarios showed that due to the temperature difference the warmer a microclimate is, within development thresholds, the faster adult olive fruit flies emerge. The time difference of first adult olive fruit fly emergence between the warmer (microclimate A) and the colder (microclimate D) microclimate was nearly a month.

When a singular universal spray, based on local authorities' practices, was added in the simulation run the olive fruit fly population in microclimates A and B is greatly affected, while in microclimate C the population is ever so slightly affected. Whereas in microclimate D the spray has no effect whatsoever on the overall population.

In conclusion, based on the results of the conducted simulation scenarios, as far as universal-spraying practices goes the existence of microclimates should be taken into account. After all, for microclimates with a colder climate the chemicals used in the spray as well as the time to apply it go to waste since it will have a slight effect on the olive fruit fly population or none at all.

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