The Role of Olive Trees Distribution and Fruit Bearing in Olive Fruit Fly Infestation

Romanos Kalamatianos[1], Markos Avlonitis[2]

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

Abstract. The role of fruit bearing percentage in olive fruit fly infestation is investigated through a simulation model where the spatial law of dispersion distances were modeled via an appropriate exponential law. The dispersal of olive fruit flies was simulated for two distinct cases, an olive grove with no olive fruits and an olive grove with 100% olive fruit bearing. Results showed that when no olive fruits were present the olive fruit flies scatter in all directions away of the starting point, while when the olive grove is full of olive fruits the olive fruit flies form a cluster around the starting position with almost zero mean travel distance.

Keywords: olive fruit fly, simulation model, olive fruit bearing, dispersion

1 Introduction

The olive fruit fly is an ancient pest that nowadays infests many olive groves worldwide and is the main cause of tremendous damage for both table olive and oil production, when no control measures are applied (Rice 2000). The olive fruit fly goes through four stages during its development, namely, egg, larva, pupal and adult. The number of generations that can appear per year depends upon local conditions, for example in Southern California six or seven generations could appear within a year (Rice et al. 2003).

Voulgaris et al. (2013) proposed a simulation model that estimates the population evolution of the olive fruit fly. The said model given real trap data as input, as well as climate data, could predict olive fruit fly outbreaks. Thus, the proposed model could be used as real-time alert system of olive fruit fly outbreaks. In their experiments, they demonstrated, that having knowledge of upcoming outbreaks could lead to estimating the appropriate time to apply population control methods.

Kalamatianos et al. (2015) build upon and upgraded the aforementioned model by inserting randomness in the development process of the immature stages of the olive fruit fly, as well as making the spatial dispersion of the olive fruit fly temperature dependent. In their experiments, it was shown how the number of starting areas in conjunction with different temperature sets and drifting distances affects the level of olive grove infestation.

Proceedings of the 7th International Conference on Information and Communication Technologies in Agriculture, Food and Environment (HAICTA 2015), Kavala, Greece, 17-20 September, 2015.

In this paper, the simulation model is modified further by making the dispersion distance of the olive fruit fly dependent on the percentage of olive fruit present inside the olive grove. This modification was based on the findings of a study done by Fletcher and Kapatos (1981) in Corfu, Greece. Through their experiments it was shown that the olive fruit fly when released in an area with no olive fruit it would travel over 400m on average in the first week. Field data from this experiment are shown in Fig. 1. On the other hand, when released in an area with 30% fruit bearing the olive fruit fly would travel on average 180m in the first week. Furthermore the time resolution of the simulations was changed from a time step of one day to one hour. Our aim is to show how the olive grove infestation is affected by the fruit bearing percentage.

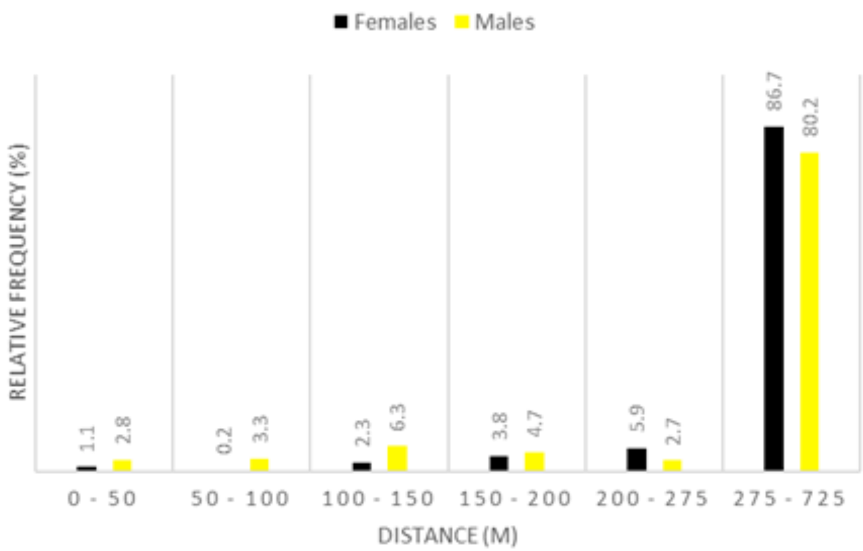

Fig. 1. Relative frequencies of olive fruit flies in an olive grove with no olive fruit bearing between 4 – 10 days after release. (Fletcher and Kapatos, 1981)

2 Methodology

2.1 Simulation Model

Initially, the grid on which the simulation will take place was constructed. The simulation model parses an image file which contains information about the field.

More specifically, each pixels color indicates the presence of olive trees (black color) or not (white color). Each cell in the constructed grid corresponded to a 10m x 10m area. Thus the minimum distance an olive fruit fly could travel inside the grid was 10m in either direction. Finally, an overlaying grid of trap cells, each corresponding to a 100m x 100m area, is constructed which are used to monitor the population size.

Each olive fruit fly passes through five transformation stages egg, larval (all instars are grouped into one stage), pupal, sexually immature adult and perfect adult. Olive fruit flies that are in one of the first three of the aforementioned stages are immobile throughout the simulation and can start drifting once they reach the fourth transformation stage.

In the initial code (Kalamatianos et al., 2015), the time resolution of the simulation was one day (one simulation step corresponds to one day), therefore the degree-day model was used for the development of the immobile population. In each simulation step, olive fruit flies that belong in the immobile population compute the degree-day units accumulated based on the temperature that was present. The following function was used to compute the accumulated degree-day units:

$$DD(t_i) = (t_i - T_L) * (1 - (1 / (1 + \exp(-10 * (t_i - T_U))))) \ . \qquad \mathbf{(1)}$$

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 insect.

All olive fruit flies that are in the perfect adult stage can reproduce and can lay up to three eggs in their lifespan and a maximum of one egg per simulation step. The total number of eggs laid by an adult olive fruit fly was selected to account for mortality in all life stages of the olive fruit fly (Kapatos, n.d.).

Drifting of the mobile population of the olive fruit fly inside the field is achieved by using the random walk model. Each insect in each simulation step computes a random distance to travel and has an equal chance to move to any direction horizontally and vertically. Although drifting inside the field is done randomly, it is also temperature dependent and is currently affected only by high temperatures. Therefore the following function is used to calculate the final distance the olive fruit fly will travel (Kalamatianos et al., 2015):

$$D(d,t_i) = d * (1 - (1 / (1 + \exp(-10 * (t_i - T_U))))) \ . \qquad \mathbf{(2)}$$

Where t_i is the temperature present in the i-th simulation step, T_U is the upper movement threshold and d the randomly computed distance to travel of each insect. The upper movement threshold was set to 35 ºC, beyond this temperature the olive flies are motionless (Avidov, 1954, cited by Johnson et al. 2011).

2.2 Modifications

For the purposes of this paper the following modifications were made to the existing simulation model.

The first modification was the change of the time resolution to one hour, thus one simulation step corresponded to one hour. This modification caused the use of the degree-hour model in place of the degree-day model, which is more accurate and doesn't underestimate heat summation (Gu et al., 2014). The following function was used to compute the accumulated degree-hour units, based upon (1).

$$DH(t_i) = DD(t_i) / 24 . \qquad \textbf{(3)}$$

Changing to an hourly based simulation, affected reproduction and drifting of the olive fruit fly, as it was possible only in hours that corresponded to the daytime of a day. Finally, as a result of the time resolution change, the area that each cell grid represented was changed to a 1m x 1m area.

The second modification was to make the travelling distance (d) in (2), of the olive fruit fly, dependent from the percentage of olive fruit present in the occupying cell. To achieve this we based our changes on the findings of Fletcher & Kapatos (1981), who concluded that when there is no olive fruit present the olive fruit flies travel an average distance of 441m (based upon their published data) in a week and when olive fruit bearing is 30% the average distance traveled, decreases to 180m in a week. Fig. 2, Curve (a), displays an exponential fit on those two points. However, one would suspect that when olive fruit bearing is 100% then there is no reasonable reason for the olive fruit fly to have a preferred moving direction. As a result we expect that the flies will perform a pure random walk stochastic procedure with almost zero mean distance from the starting point. Therefore, based on the previous mentioned assumption, we applied an exponential fit on the following points, for 0% of olive fruit presence olive fruit fly travels an average distance of approximately 450m a week and for 100% olive fruit presence the average distance decreases to approximately zero meters a week (Fig. 2, Curve (b)). It is noted that since the average distance between olive trees is about 5m to 10m and a non-uniformity of fruit bearing between neighboring trees may be emerged we may observe an average deviation of 5m to 10m of cluster center from the initial position.

Thus, the following function was used to calculate the distance to disperse based on fruit percentage:

$$d(x, y) = (451.8 * \exp(-0.04098 * fp(x,y))) / wh . \qquad \textbf{(4)}$$

Where fp(x,y) is the olive fruit percentage on (x,y) coordinates of the grid and wh the total daytime hours in the current week. It is important to note that the minimum distance an olive fruit fly can travel inside the simulated grid was 1m.

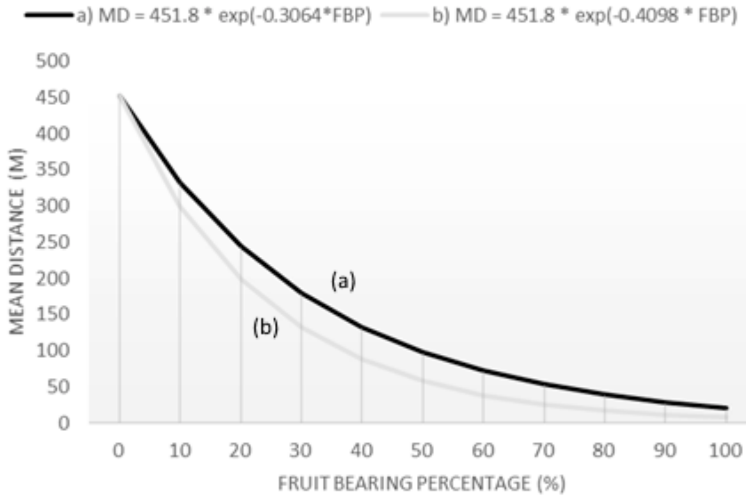

Fig. 2. Exponential laws for the mean traveled distance of olive fruit flies. Curve (a) corresponds to the field measurements (Fletcher and Kapatos, 1981), curve (b) exponential law reproducing no preferred direction for 100% fruit bearing.

It is noted that a discrepancy between the field data of Fletcher and Kapatos (1981) and our estimation for the value of 180m mean dispersion distance is emerged. This could be explained by the difficulty to accurately measure olive fruit bearing. It is easy to estimate olive grove of 0% or 100% fruit bearing but this is not the case for bearing values between those limited values.

Furthermore we modified the random walker model used by the olive fruit flies to disperse inside the field in the following way. Each olive fruit fly starts with a 50% chance to move left or right and up or down. Based on the olive fruit percentage of the cell it moves, the chance to move in the same direction increases, which subsequently means that the chance to move on the opposite direction decreases. If the olive fruit fly moves to a cell with different fruit percentage than the previous one then the chance to move in either direction is reset to 50% and the process is repeated.

2.3 Simulation scenarios

For the following simulation scenarios the immobile population is not taken into consideration since only the dispersion of adult olive fruit flies for a limited time period of one week was considered.

Two simulation scenarios were conducted. For both scenarios dispersal was done inside a 1500m x 1500m area of olive grove. The simulation time was 168 steps which corresponded to one week. 10000 adult olive fruit flies were placed in the center of the field and started dispersing once the simulation started. Hourly temperatures used for the simulation period were from the year 2014 (obtained from

Meteo.gr (2015)). The daytime period for all the days of the simulation period was set to 14 hours. For the first scenario it was assumed that no olive fruit was present inside the olive grove, where the simulation took place. On the other hand for the second scenario it was assumed that the fruit percentage was 100%.

3 Results

Fig. 3 displays snapshots of the dispersal of the olive fruit flies inside the field, for the first simulation scenario, by the end of 2, 4 and 7 days after the simulation started. On the end of the second day, the olive fruit flies are still forming a cluster around the starting position.

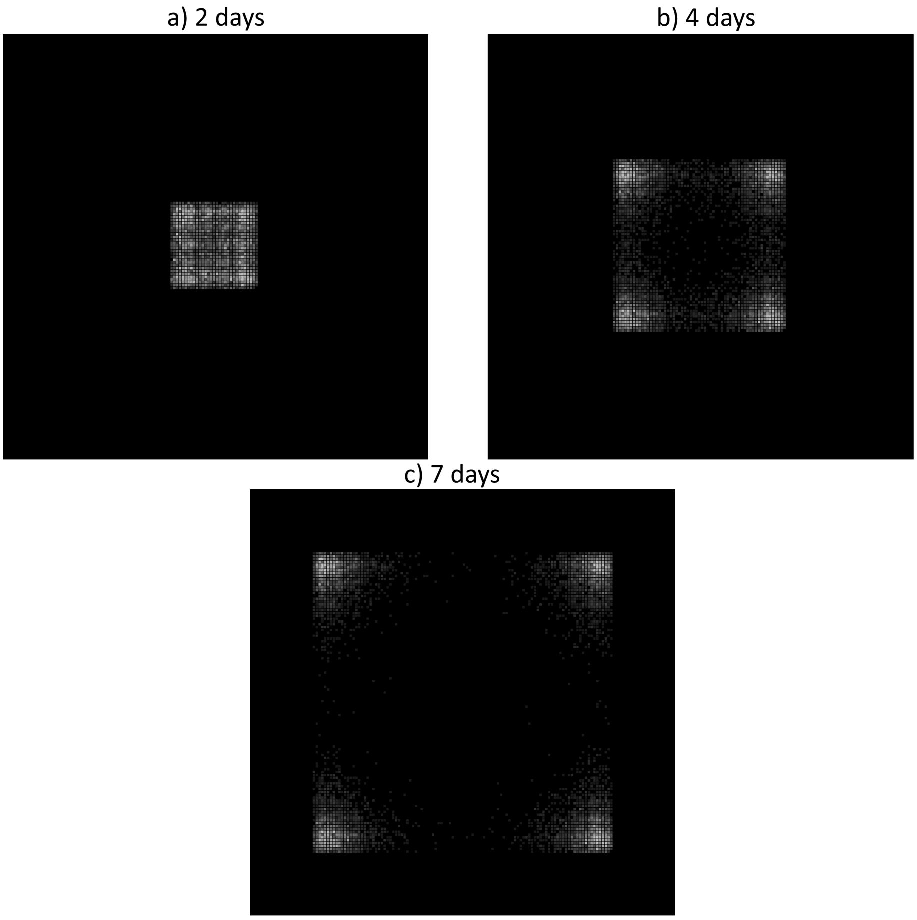

Fig. 3. Dispersal of olive fruit flies for second simulation scenario (a) 2 days, (b) 4 days and (c) 7 days after simulation started. White colored cells are occupied cells, black colored cells are unoccupied cells.

By the end of the fourth day the previous cluster has expanded on all directions and by the end of the seventh day four main clusters can be observed heading for the corners of the field with a few areas in between being infested while no presence of olive fruit fly can be seen around the starting position.

Fig. 4 displays the distribution of the final position of the olive fruit flies in relation to their starting position, for the first simulation scenario. Olive fruit flies near the starting position were very few for both axis, while when moving away from the starting position in either direction the frequency of olive fruit flies starts to increase. It can be seen that the final olive fruit flies distribution in time and space coincide with the field findings in Fletcher and Kapatos (1981) as depicted in Fig. 1.

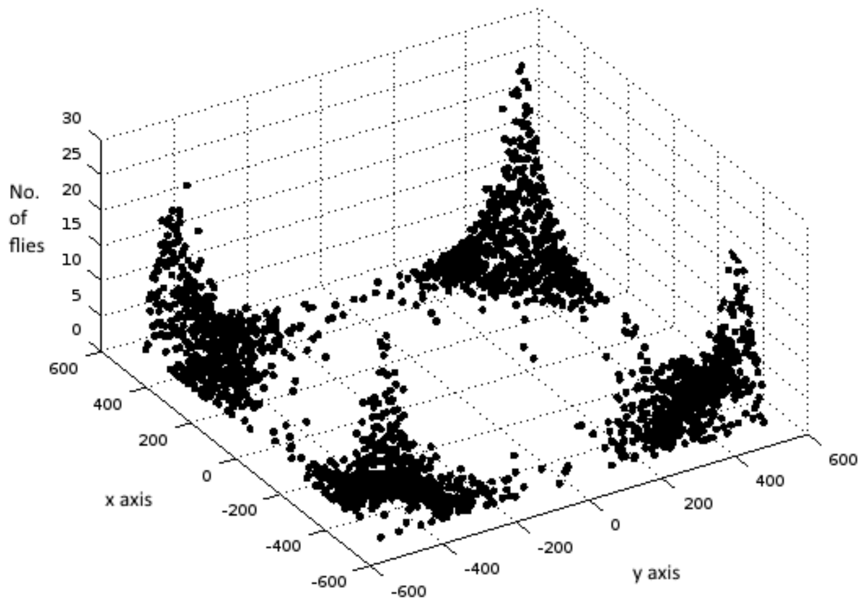

Fig. 4. Distribution of final positions in relation to the starting position of the olive fruit flies.

For the second simulation scenario, Fig. 5 displays snapshots of the dispersal of the olive fruit flies inside the field by the end of 2, 4 and 7 days after the simulation started. On the end of the second day, the olive fruit flies are forming a cluster around the starting position. By the end of the fourth day the previous cluster has expanded by a few meters on all directions while a great number of olive fruit flies is still around the starting position. Finally, by the end of the seventh day the cluster around the starting position still holds although it has expanded further since the fourth day, again by a few meters.

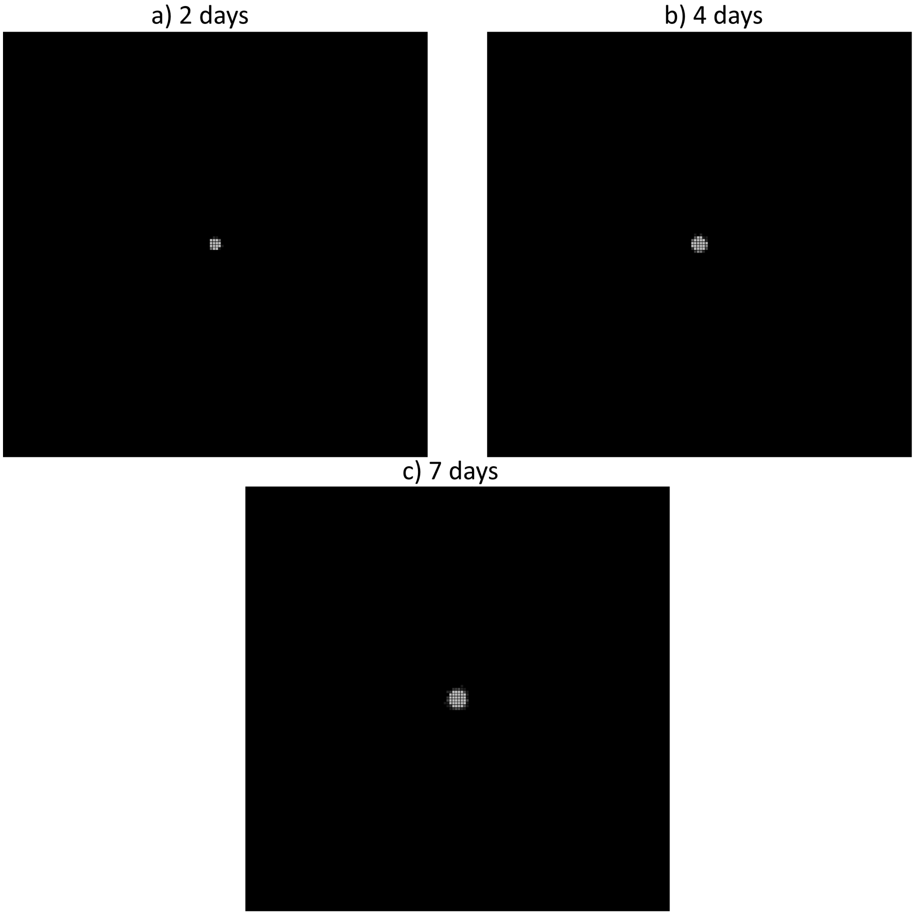

Fig. 5. Dispersal of olive fruit flies for the second simulation scenario (a) 2 days, (b) 4 days and (c) 7 days after simulation started. White colored cells are occupied cells, black colored cells are unoccupied cells

Fig. 6 displays the distribution, for both axis, of the final position of the olive fruit flies in relation to their starting position, for the second simulation scenario. As one can see the distribution of the flies follows a normal distribution.

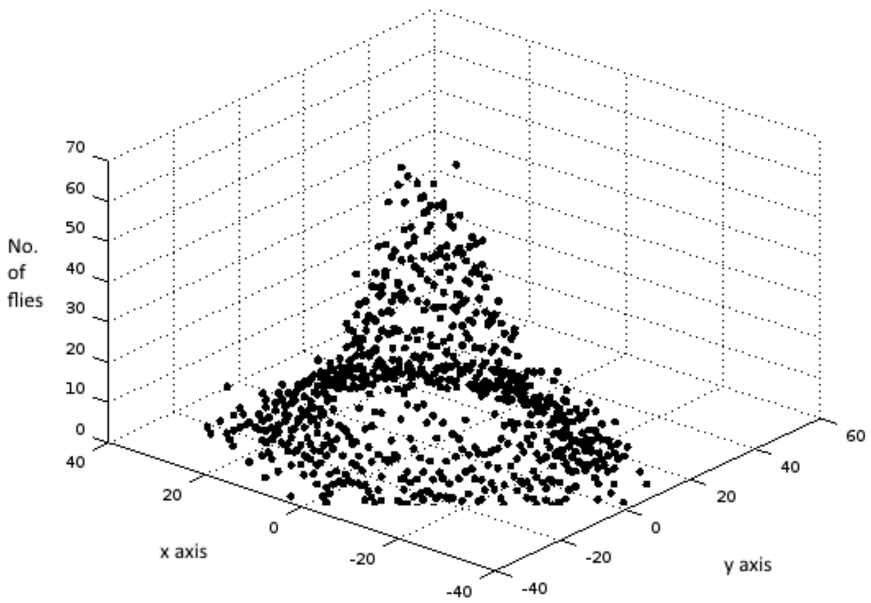

Fig. 6. Distribution of final positions in relation to the starting position of the olive fruit flies.

4 Discussion

Our simulation model was modified in order for the dispersal distance of the olive fruit fly to be depended by the fruit percentage inside the olive grove it resides. Additionally, the time resolution of the simulation model was changed to one hour, for more accurate results.

When the olive fruit flies were placed in an olive grove without new olive fruits they started scattering in all directions away of the starting position and by the end of the week none was near the starting position. On the other hand, when placed in an olive grove with 100% olive fruit after a week all olive fruit flies had dispersed around the starting position forming a cluster around it.

Finally, although Fletcher and Kapatos (1981) showed that for a fruit percentage of 30% olive fruit flies traveled an average of 180m in a week, according to the function we used to calculate the mean distance that an olive fruit fly would travel based on the fruit percentage, this distance corresponds approximately to 25% olive fruit bearing.

Acknowledgments. Financial support of the European Union and of National Funds of Greece and Albania under the IPA Cross-Border PROGRAMME "Greece -

Albania 2007 -2013", project title “Enhancing Olive Oil Production with the use of Innovative ICT” with the acronym “e-Olive”, is gratefully acknowledged.

References

1. Fletcher, B. S. and Kapatos E. (1981) Dispersal of the olive fly, Dacus Oleae, during the summer period on Corfu. Exp & appl. (29):1-8.
2. Gu, S., Sabuwala, A. and Gohil, H. (2014) Comparison of Growing Degree Hours Based on Hourly Average Temperatures with Growing Degree Days Based on Daily Minimum and Maximum or Average Temperatures to Interpret Heat Summation. American Society for Horticultural Science. Orlando, FL, USA.
3. Johnson, M., Wang, X., Nadel, H., Opp, S., Lynn-Paterson, K., Stewart-Leslie, J. and Daane, K. (2011) High temperature affects olive fruit fly populations in California’s Central Valley. Calif Agr 65(1):29-33. DOI: 10.3733/ca.v065n01p29.
4. Kalamatianos, R. Stravoravdis, S. and Avlonitis, M. (2015) Complex networks and simulation strategies: an application to olive fruit fly dispersion. 6th International Conference on Information, Intelligence, Systems and Applications. Corfu, Greece.
5. Kapatos E. (n.d.) The Bionomics of the olive fly, Dacus oleae (Gmelin) (Diptera: Tephritidae), in Corfu. Unpublished PhD thesis, University of London.
6. Meteo.gr. (2015) [Online] Available at: http://www.meteo.gr/meteoplus/index.dfm [Accessed: 06 July 2015]
7. Rice, R. (2000) Bionomics of the Olive Fruit Fly Bactrocera (Dacus) olea, UC Plant Protection, 10(3).
8. Rice, E. R., Phillips, A. P., Stewart-Leslie, J. and Sibbet G. S. (2003) Olive fruit fly population measured in Central and Southern California. *California Agriculture* 57(4):122-127. DOI: 10.3733/ca.v057n04p122
9. Voulgaris, S., Stefanidakis, M., Floros, A. and Avlonitis, M. (2013) Stochastic modeling and simulation of Olive Fruit Fly outbreaks. Procedia Technology. Volume 8, Pages 580-586, ISSN 2212-0173, http://dx.doi.org/10.1016/j.protcy.2013.11.083.