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Developing an algorithm model for Controlling Bactrocera oleae, in Olive Orchards in the South Region of Lebanon, by Using Conventional Traps

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Developing an Algorithm Model for Controlling *Bactrocera oleae*, in Olive Orchards in the South Region of Lebanon, by Using Conventional Traps

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Abstract: Modern agriculture requires technology to give precise measures about relevant parameters such as pest control. Here, we developed an algorithm model as base for bait spray intervention, by monitoring the olive fruit fly, *Bactrocera oleae* (Rossi), with conventional traps, in 24.3 Hectares of non-irrigated Baladi olive cultivars, in Hassbaya region. We installed 49 yellow sticky traps with ammonium bicarbonate. The adults, males and females were monitored, on weekly basis. The traps and the trees were georeferenced, and the parameters such as temperature, relative humidity, tree phenology (BBCH), and fruit load rate were compiled. The results showed that the infested fruits were correlated as much with the fruit load rate as with the number of adults captures which were correlated more to the temperature than the relative humidity. The number of the males captured was higher than the females all over the cultivation period. The first symptoms of the fruits were observed from 22 September when the BBCH was equal to 85%, with an average of adult captures lesser than 5 adults by trap by 7 days.

Keywords: olive fruit fly; conventional traps; pest monitoring; algorithm for intervention

1. Introduction

The olive fruit fly, *Bactrocera oleae* Rossi (1790) (Diptera; Tephritidae), is the primary insect pest in all olive growing regions worldwide including Lebanon where this tree is considered one of the most important cultivated crops [1], and causing economic losses [1–4]. The adult females deposit its eggs (50-400eggs in her lifetime) under the skin of the fruit [5]. The Larvae develop and feed on the pulp of the fruit. Infested fruit sometimes dropped prematurely. Secondary infestation of bacteria and fungi accumulated in the tunnels made by the larva inside the fruit decreases oil quality [6,7]. Thus, in years with high fly population damaged fruit cannot be processed as olive table, and in the case of olive oil production, *B. oleae* directly affects the amount and the quality of the oil by increasing of the acidity degree [6,7]. The flies are very mobile and have the ability to seek out cooler areas of the orchard and urban trees. Its mobility and the fact that generations overlap, make the treatment of this insect complicated task [8–10]. Therefore, the activity of *B. oleae* is influenced by several factors including latitude, altitude, tree load, irrigation [11], temperature [12], relative humidity [13], variety [14], physicochemical characteristics of drupe [15] and parasite activity [16]. In Lebanon, coverage chemical spraying is the main option used to control *B. oleae* [4]. Compare to its aggression mode, the control of the olive fruit fly is highly complex as conventional chemical control remains ineffective having negative impact on the environment and human health, with associated problems of resistance, side effects on beneficial insects [17,18]. There are alternative control measures for this important pest which are more environmentally friendly, such as Spinosad under bait spraying based on the monitoring of the pest population through several kind of traps especially, yellow sticky Traps [19–22]. Thus, the objectives of this study were to evaluate the critical parameters for taking decision

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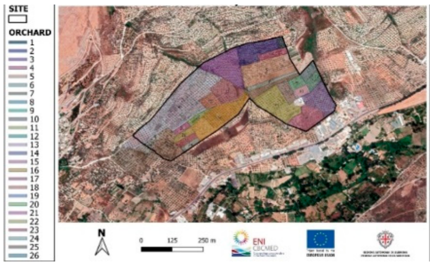
to know when, where and how to spray, especially the number of the adults captured by yellow sticky traps added with the attractant Ammonium bicarbonate, the observations of the infested fruits coupled with climatic data (temperature, relative humidity, etc…), the phenological characteristics of the tree, especially the fruit load rate.

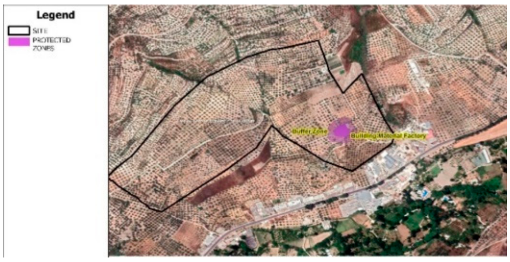
2. Material and Methods

2.1. Experimental Site

The Site was located in south Lebanon at Hassbaya Region. The coordinates were: Latitude 33°23'53.00"N and Longitude 35°41'5.70"E, with an elevation between 525 to 600 meters a.s.l (Goto: location : 33.382030, 35.718210) (Figure 1).



(a)



(b)

Figure 1. (a) Area of the experimental Site owned by 26 farmers; (b) Protected zones in the Site composed by cement manufactory.

2.2. Trees and practices

The site was not flat and very heterogeneous in term of topography: It represented a lot of variation in altitude (almost 75 m of difference at max.) showing many hills and valleys. Owned by 26 farmers with a total area of 24.3 Ha, the site was composed by non-irrigated Baladi cultivar with different clones. This cultivar is characterized by a high tolerance to the drought and moderate tolerance to the OFF. The same agricultural practices were registered despite the variation in tree age, 20-70 years old, and in tree distances, 5 to 8 m giving a density of 250 to 350 trees by ha, or 5353 Trees as total number in 24.3 ha. Tree height is ranging between 3 and 7 m, with canopy diameter between 3×3 m and 7×7.5 m. The fruit load rate of the trees was achieved on 13 August (Figure 2). Pruning was not severe, weeding was almost absent, spraying was not registered from years. An addition of the animal manure by the farmers in late September was registered.

TreeID	SpeciesID	Date	Label	Height	Diameter	Longitude	Latitude	Altitude	Notes	InTheRow	Row	ZED	Rank of fruit load	fid
1	1	8/13/2022		3	4	35.65472	33.40318	595		0	0	0	25-50	4777
2	1	8/13/2022		3	4	35.65475	33.40319	595		0	0	0	25-50	4778
3	1	8/13/2022		3	4	35.65479	33.40318	595		0	0	0	25-50	4779
4	1	8/13/2022		3	4	35.65486	33.4032	595		0	0	0	25-50	4780
5	1	8/13/2022		3	4	35.65471	33.40313	595		0	0	0	25-50	4781
6	1	8/13/2022		3	4	35.65475	33.40315	595		0	0	0	25-50	4782
7	1	8/13/2022		3	4	35.65482	33.40316	595		0	0	0	25-50	4783

(a)

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(b)

(c)

(d)

Figure 2. (a) output of the OliveFlyNet applications interface showing details about information stored in the geodatabase system; (b) Tree Location Map; (c) Verronoï polygons of the Trap zones; (d) Tree Picture.

2.3. *Trap Installation*

The Trap Installation was realized on 22 July 2022, and the Trap ID added to the Tree ID was registered (Figure 3).

TreeID	SpeciesID	Date	Height	Diameter	Longitude	Latitude	Altitude	Trap	Ranking of the Fruit load
91	1	8/13/2022	3	4	35.65420861	33.4029652	581	T31+	25-50
260	1	8/13/2022	3	4	35.65325639	33.40275566	581	T32+	25-50
422	1	8/13/2022	3	3	35.65229399	33.40240353	591	T25+	0-25
451	1	8/13/2022	3	3	35.65168866	33.40195652	591	T24+	0-25
604	1	8/13/2022	3	3	35.6529581	33.40220971	591	T26+	0-25
661	1	8/13/2022	3	3	35.65230505	33.40149263	591	T23+	0-25

Figure 3. Output of the OliveFlyNet applications interface showing details about information stored in the geodatabase system.

We installed 49 Yellow Sticky Traps (2 Traps / ha) added with ammonium bicarbonate in small bag (10g) (Figure 4).

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Figure 4. Yellow Sticky Traps (2 Traps / ha) added with ammonium bicarbonate in small bag (10g).

The Traps numbered from T1+ to T49+). The distance between two Traps was 100m. The size of the yellow panel was 14 x 20cm; and we used only one side. Traps were placed in the same way, at 1.8 m high, to the south part of the canopy. The Traps were renewed weekly.

2.4. Meteorological Data Monitoring

The sensors weren't applicable. The climatic data was registered from the LARI Weather Station installed far 3 km from the Site (Figure 5).

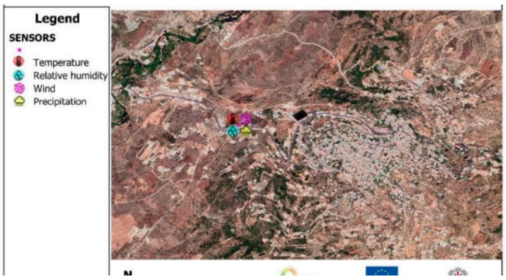

Figure 5. LARI Weather Station at Hassbaya Region.

The Hasbaya AWS of DIAM at LARI is Evapotranspiration iMETOS 3.3 by Pessl Instruments (https://metos.at/), located at latitude 33.4009732°, longitude 35.6772606° and altitude 873 m. It started recording data since mid-December 2013. This iMETOS 3.3 powered by rechargeable battery and a solar panel. It is versatile, with the possibility to configure and connect many different sensors – over 600 sensors could be hooked through the intelligent sensor bus system. The data logger has a built-in UMTS/CDMA modem for direct communication (GPRS) with the Field Climate Web Platform. The system may store up to 8 MB of logged data. Data is regularly uploaded to Field Climate Web Platform with the possibility of 15 minutes recording frequency. Reference Evapotranspiration is a daily calculated parameter. The Hasbaya AWS is equipped with the following sensors: - Precipitation (mm) - Air Temperature (°C) (Dew Point temperature is then estimated) - Relative Humidity (%) - Wind Speed (m/s) - Solar Radiation (W/m2) - Wind direction (degrees) - Atmospheric Pressure (kPa) - Reference Evapotranspiration (ETo mm by day) (Calculated through FAO Penman-Monteith Equation). Thus, meteorological data was recorded during the whole experiment, at an interval of 15 min. The major parameters registered are: the temperature (average, Maximum, Minimum), the relative humidity (average, Maximum, Minimum), the speed wind, and the precipitation were registered from the beginning, 22 July till the end of the experiment, 10 November.

2.5. Parameters Studied to Take Decision for Spraying

2.5.1. Pest Captures

Bactrocera olea is the pest target in this experiment. Counting of the adults, males and females, were carried out at weekly basis. We marked the females by a red circle, and the males by a blue circle. The observations were began on 29 July and achieved on 10 November.

2.5.2. BBCH Value

The Phenological Stage Events of the olive were observed and followed in BBCH centesimal scale adopted by the PHENAGRI [23–25]. Thus, we reported when we obtained a BBCH A= 75 (50% of its Final Size), or B = 80-85% (fruit becoming light Green or yellowish), or C > 85-89% (harvest Maturity). The BBCH was observed and registered from 29 July till 10 November. Dimensions (W×L, Size) of the olive fruits were taken from 5 August till 15 September (examination of 6 fruits per zone Trap; total of 250 fruits) (Figure 6). Then, another dimension registration was realized on 3 November (12 fruits per zone Trap; total of 588 fruits).

Figure 6. Fruit Observation and Dimensions (W × L; Size), and Rate of the Fruit Infestation Registrations.

2.5.3. Rate of Fruit Infestation, RFI

We collected, randomly, and examine 6 fruits per zone Trap till September 22 (total of 250 fruits) ; after this date, we had collected 12 fruits per zone Trap (total of 588 fruits) to have more representative samplings knowing that the rate of infestation would be increased, and the fruits were collected in three separate bags related to the Three Fruit Load Rate obtained and numbered with three zone Traps: 1= 50-75%, 2 = 25-50% and 3= 0-25%; the calculation of these rates was in relation with the scale of the fruit production [26–30].

Each fruit was examined at LARI Laboratory at Tel Amara and if needed under Stereoscope, to count the infested fruit. A fruit infestation was considered if there is one of these symptoms: presence of 1) Egg cone or plenty egg, 2) larva at the first second or third stage, 3) pupa (empty or present), or 4) empty hole (Figure 6).

2.6. Statistical Data Analysis

All the data collected weekly related to the Dimensions of the Fruits, the BBCH of the fruits, the Rate of the Fruit Infestation, the Adults (Females and Males) Captures, were treated statistically, by the multiple comparison of the mean by date and by trap zones, by following ANNOVA tests (Tukey Tests, $p < 0.05$) if the data represented a normal distribution, or Kruskall-Wallis Tests ($p < 0.05$) if the data wasn't follow a normal distribution. Linear regression tests (Pearson Correlation) were realized between the flies captures and the temperature and the relative humidity registered, respectively. All these analysis were treated, by using SigmaStat plot software [31].

3. Results

3.1. Monitoring of the Adults

The means followed by the high values of the standard deviations were observed during the whole period of the experiment, and underline the high variation values in the total number of adults (females marked by red circle, and males by blue circle – Figure 7) from trap to trap per date (Figures 8–10). This would be related to the age of the trees, or to the variation in the fruit load rate, or the heterogeneous topography of the site where the climatic conditions (T and RH) must be registered close to each trap by sensors and not from the weather station which located far from the trees. Therefore, we have to mention that the farmers began their fruit harvesting on 10 October and lasted one month.

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Figure 7. Sample of Yellow Sticky Traps added with Ammonium Bicarbonate in plastic bag (10g).

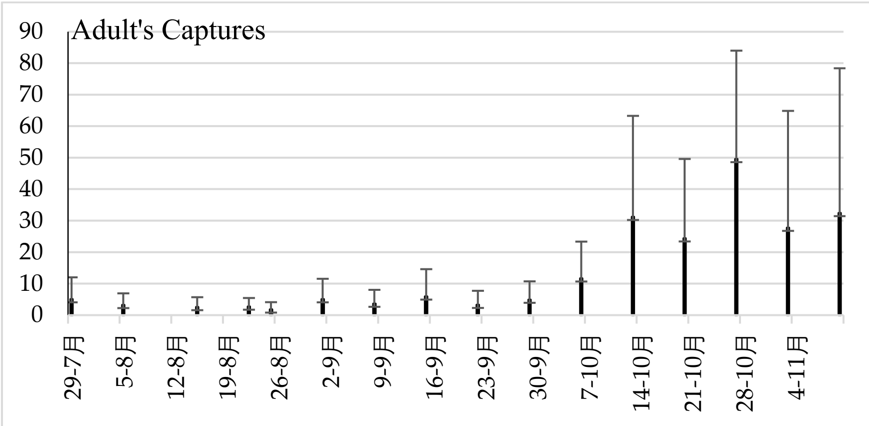

Figure 8. Means and Standard Deviation of the Adult's Captures by Trap by date (49 Yellow Sticky Traps with Ammonium Bicarbonate in 24.3 ha).

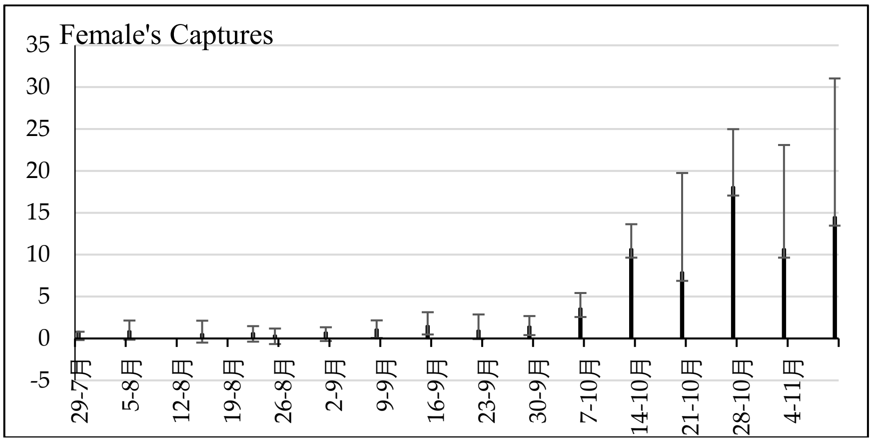

Figure 9. Means and Standard Deviation of the Female's Captures by Trap by date (49 Yellow Sticky Traps with Ammonium Bicarbonate in 24.3 ha).

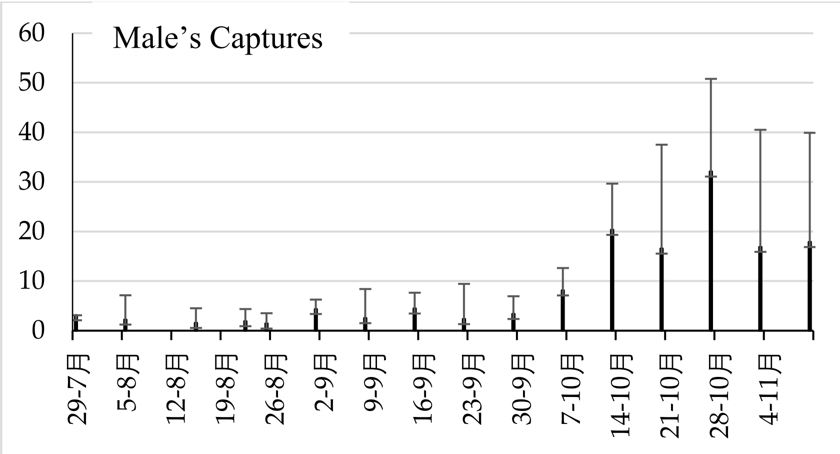

Figure 10. Means and Standard Deviation of the Male's Captures by Trap by date (49 Yellow Sticky Traps with Ammonium Bicarbonate in 24.3 ha).

3.2. Adult Abundance

The average number of the Adults remained low until 22 September where it reached 4.19 Adults/Trap/Week; then it increased progressively from 7 October till 10 November with an average of 12 and 18.4 Adults/Trap/Week, respectively (Figure 8).

The captures were registered in GIS system. Some map Samples extracted from the Geodatabase system (Figure 11-a, 11-b, and 11-c) showed the variation, by date, of the flies' numbers, Adults, females or males, respectively.

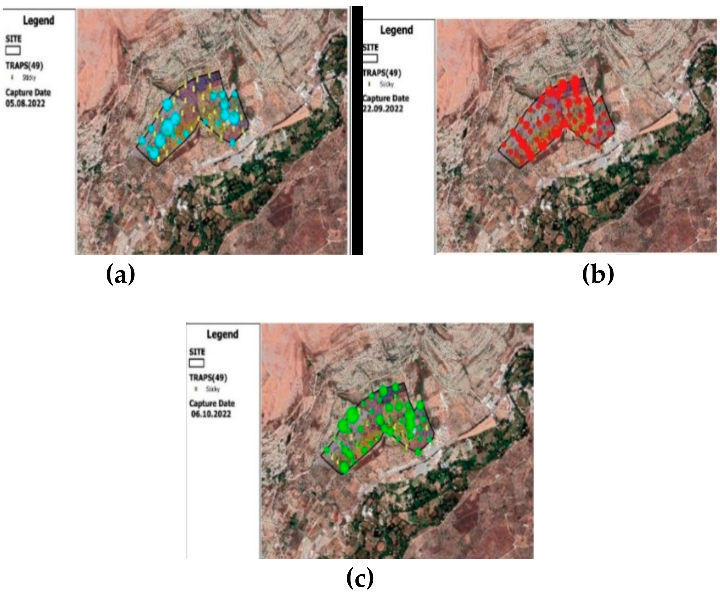

Figure 11. *Bactrocera oleae*'s Captures by Trap by date in the Developing of Decision Support System Site (49 Yellow Sticky Traps with Ammonium Bicarbonate in 24 Ha); (a) Males captures on 5 Aug.; (b) Females Captures on 22 Sep.; (c) Adults captures on 6 Oct.

Thus, examples of the interpolated maps of adult's captures (Figure 12) registered on the traps weekly and extracted from the geodatabase, showed also the huge variation in the captures from trap to trap at the same date.

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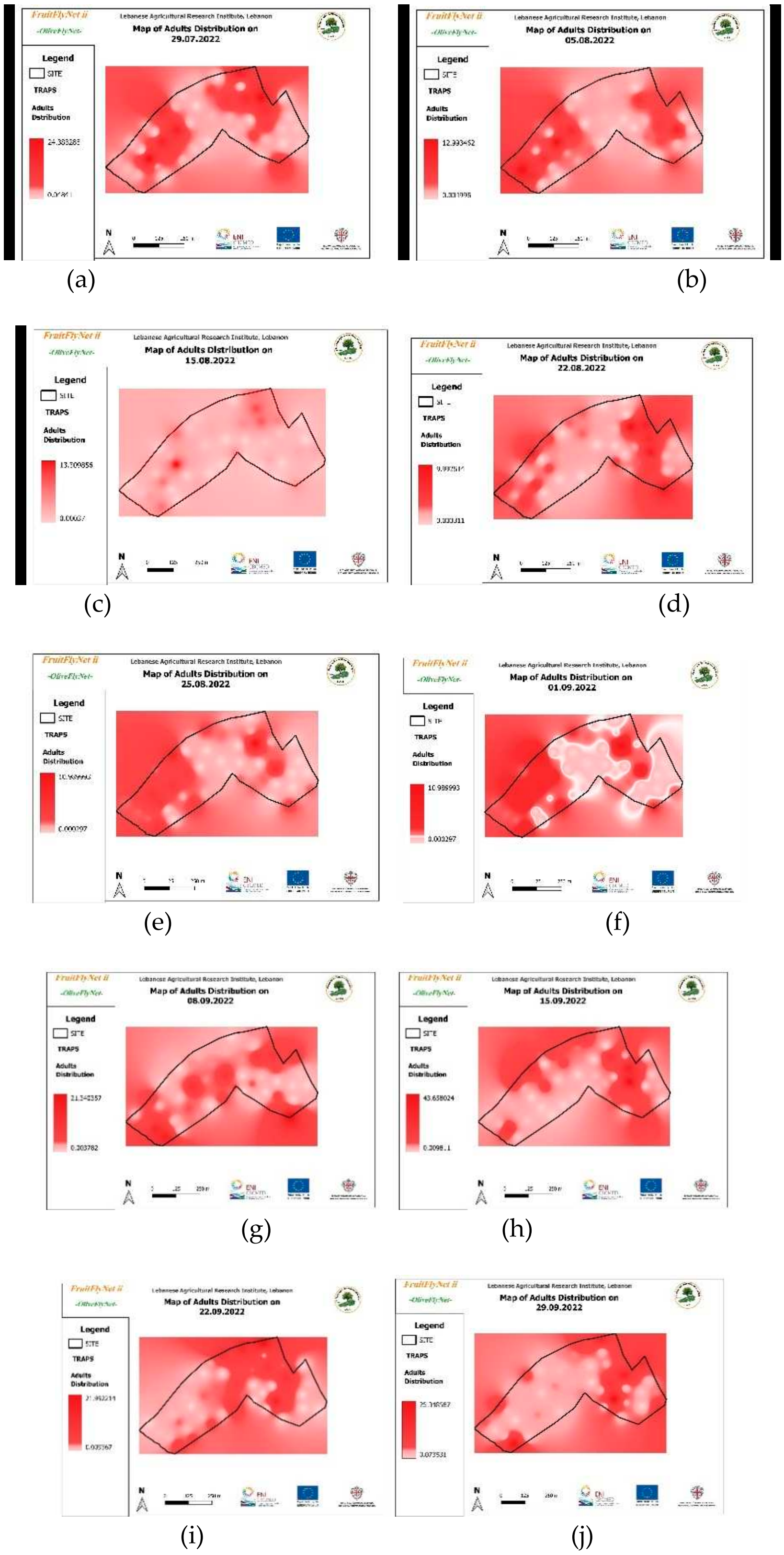

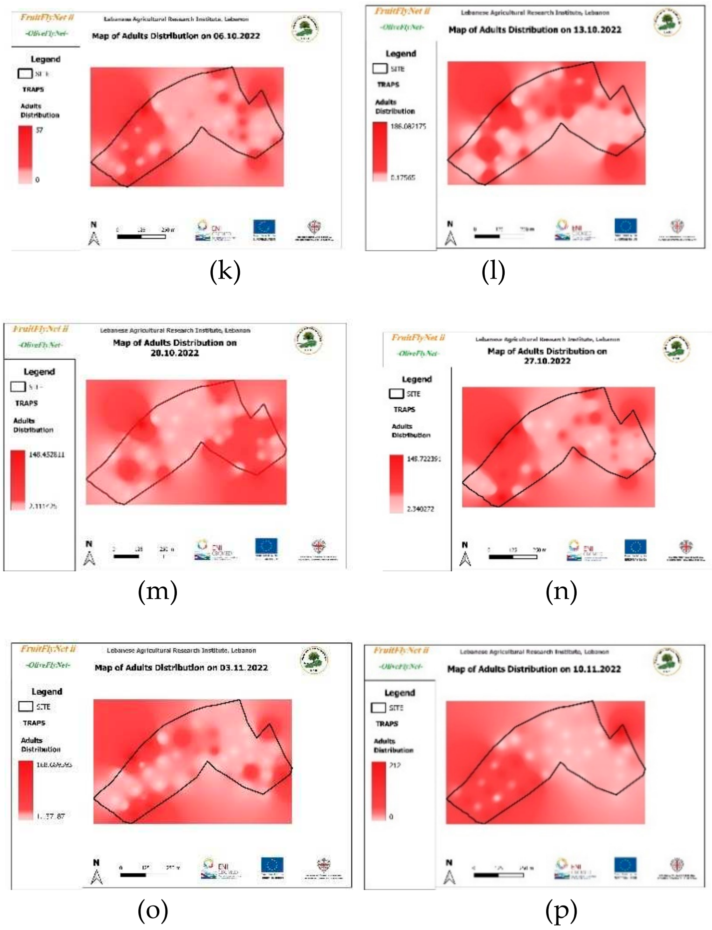

Figure 12. Interpolated maps of *B. oleae* Adult's captures on yellow sticky traps with ammonium bicarbonate, from 29 July till 10 November 2022: (a) 27 Jul.; (b) 5 Aug.; (c) 15 Aug.; (d) 22 Aug.; (e) 25 Aug.; (f) 01 Sep.; (g) 08 Sep.; (h) 15 Sep.; (i) 22 Sep.; (j) 29 Sep.; (k) 6 Oct.; (l) 13 Oct.; (m) 20 Oct.; (n) 27 Oct.; (o) 3 Nov. ; (p) 10 Nov.

These high variations observed in the Adults (Females and males) captures were also reported in other Mediterranean regions and even in Subhumid climate (Essaouira–Maroc, and Mezghenna–Algeria and Egypt). In fact, it was observed that the olive fruit fly populations fluctuate over time and from trap to trap and from one period to another [32–36].

3.3. Spatial and Temporal Distribution of Bactrocera oleae Adults

Temperature and Relative Humidity were recorded on a daily basis by the LARI weather station installed at 873m. a s l. On the other hand, the min, average, and max values, for either the registered daily temperatures or the relative humidity, were very close to each other, which didn't reflect necessarily the real situation, near the Trap. Therefore, the season was practically dried without almost rain all the time. We noticed two critical period where the Relative Humidity was very low (30 - 40%). In fact, the first was between 15 and 31 August, with an average of temperature between 27 and 30 °C; and the second was between 27 September and 2 October, with an average of temperature between 23 and 29 °C (Figure 13). Therefore, in El Fayoum – Egypt (dry region), they indicated that the relative humidity had a positive effect on the numbers of the olive fruit fly during 2017 cultivation periods using McPhail Traps and Yellow Traps [36], while many studies showed the effect of the temperature on the number of flies captures [37,38].

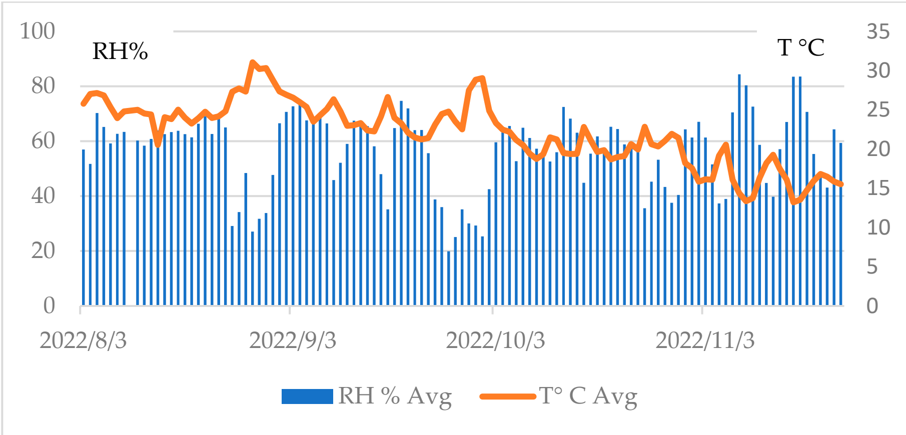

Figure 13. Average Temperature (°C) and Relative Humidity (%) on a daily basis.

Thus, the density of the fly captures increased from the first week of October. Thereafter, the temperature decreased progressively from the first week of October (from 23 till 13 °C on 10 November), while the Relative Humidity was fluctuating between 40% till 80% (Figure 13). Our Statistical analysis showed that the captures were negatively correlated to the temperature with y=-3.36x + 88.96; r = 0.785 (Pearson Correlation) (Figure 14).

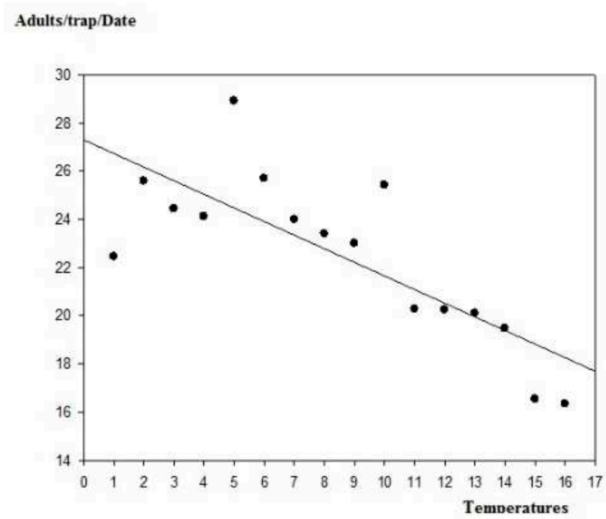

Figure 14. Linear regression between Temperatures registered and the adult's captures.

3.4. Sex Ratio

Our observations showed that the male's captures were higher than the female's captures (Figure 15) during the whole experiment, with a sex ratio ranking between 0.2:1 and 0.83:1 (F:M) at the end of the cultivation period (Table 1).

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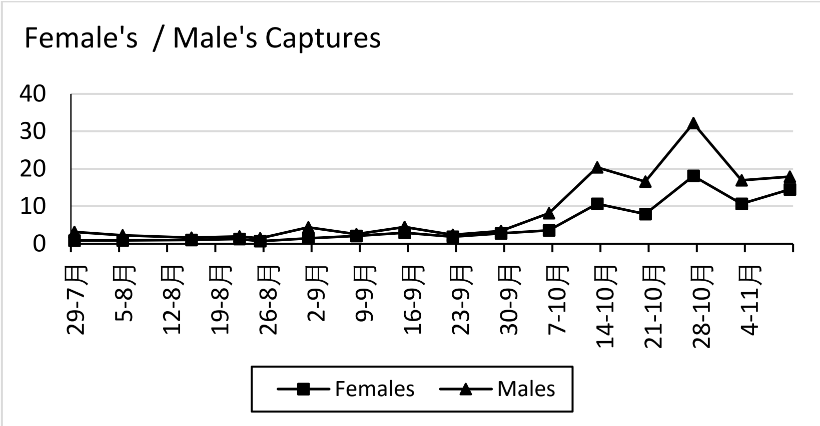

Figure 15. Repartition of the females and males in the whole area (24.3 ha).

Table 1. Sex Ratio of *B. oleae* during the experiment period (F:M).

Dates	29-Jul	5-Aug	15-Aug	22-Aug	25-Aug	1-Sep	8-Sep	15-Sep
Sex Ratio	0.2:1	0.41:1	0.64:1	0.42:1	0.47:1	0.32:1	0.89:1	0.65:1
Dates	22-Sep	29-Sep	6-Oct	13-Oct	20-Oct	27-Oct	3-Nov	10-Nov
Sex Ratio	0.78:1	0.82:1	0.44:1	0.53:1	0.48:1	0.56:1	0.64:1	0.83:1

However, some studies reported a sex ratio close to 1:1 [11,39,40], while others [41,42] observed a slightly higher number of males (52.2% males) than the females.

3.5. BBCH and fruit Dimensions

The Olive Fruits reached half their size on the beginning of August, and still green till the first week of September, the beginning date of the colour turning (BBCH: 80-81%) (Figure 16).

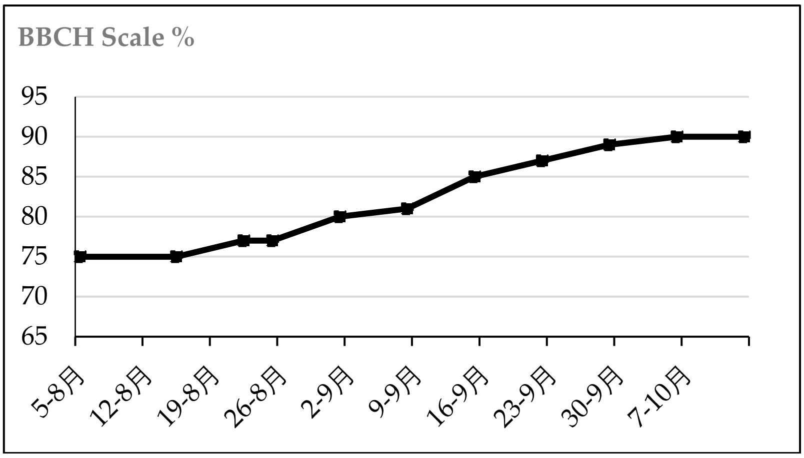

Figure 16. BBCH scale indicating the Phenology of the olive trees.

Progressively from September 15th, some of the olive fruits turned to the purple colour. It is important to notice that even at the end of the experiment (10 November), the fruits represented four Colour: green oily, green brown, purple, and black- purple. The Olive fruits lose size during the drought period, 22 August till the first of September; and from the first week of September they have gained size again (Figure 17).

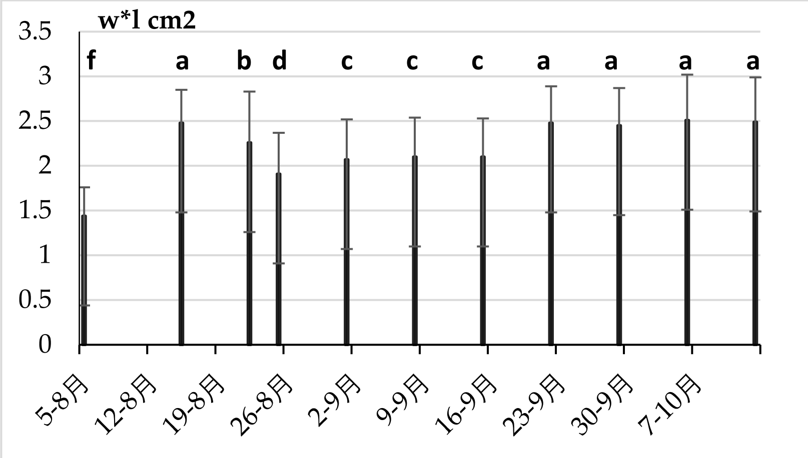

Figure 17. Size of the olive fruit during the experiment.

But the size gain of the olive fruit would be related to the percentage of the fruit load rate (Table 2). Many studies showed the effect of the fruit load rate, the age and the variety on the Fruit size [27–29].

Table 2. The size of the olive Fruit registered by the rate of the fruit load.

Fruit Load Rate	Width	Length	Size
50-75%	1.11±0.11	1.78±0.24	1.98±0.36 b
25-50%	1.21±0.17	1.98±0.21	2.4±0.52 a
0-25%	1.18±0.2	1.97±0.24	2.34±0.57 a

3.6. Fruit Infestation

From 5 August to 15 September, the olive fruits showed only unfertile punctures or "white punctures" (less than 0.1 mm); Thus, these fruits maintained in the laboratory for one week, they didn't register any hatching larva neither any egg or any other symptom. Eggs, larvae, pupae and empty holes of the OFF attacks started to show up from 22 September (Figure 18). Thus, our observations showed that the rate of the fruit infestation, RFI, remained equal to zero till 15 September; Then, the first symptoms were registered on 22 September with RFI 0.4% and 1.5%, in the tree zones with 25-50% and 0-25% fruit load rate, respectively. The RFI remained below 2% until 3 November where the tree zones with 0-25% fruit load rate, it reached 2.27%. At the end of the experiment (10 November), the RFI reached 4.4% and 3.7%, in the tree zones with 25-50% and 0-25% fruit load rate, respectively; these two RFI values registered in this date were biased by the decreased number of the olives due to the end of the fruit harvest. On the other hand, it is important to mention that the OFF attacks were absent in the tree zones with a fruit load rate between 50 and 75%. Field evaluation of the susceptibility of mill and table olive varieties to egg-laying of olive fly was studied in Sicily and Spain and the results showed that the percentages of fruit infestation increased as the olive fruit increased in diameter [43,44].

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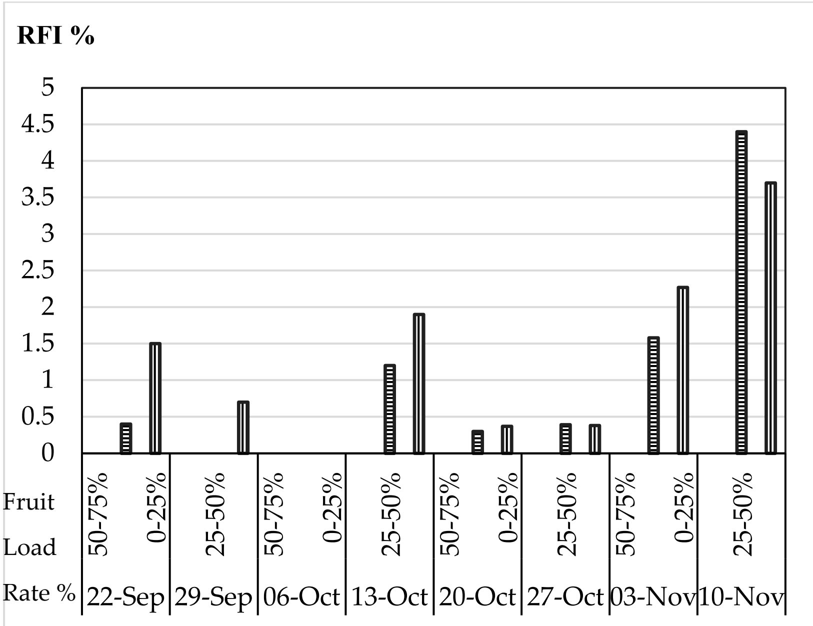

Figure 18. The Rate of the Fruit Infestation RFI % observed during the experiment in relationship with the Rate of the Fruit Load registered (50-75%, 25-50%, or 0-25%).

4. Discussion

Trap captures constitute the major data source for olive fruit fly population analyses. The attractiveness of yellow sticky traps to olive fruit flies was significant but varied over the cultivation period with higher attraction effects on the males than the females. Many studies showed this kind of variation with different effects on the two sexes of wild populations [42,45–49]. The first symptoms were registered on 22 September where the BBCH was close to the harvest period (85-87%) and the mean captures of adults equal to 4.19 adults (1.84 and 2.35 female's and male's captures, respectively - Figure 15). In fact, the RFI was more pronounced in the tree zones with 0-25% fruit load rate (RFI = 1.5%). We have to mention that the tolerable fruit damage threshold for table fruits is 1% and it is 10% for olive oil production in Europe [50]. The increasing number of the adult captures observed from the first week of October, would be related to the decreasing of the temperature values (below than 25°C). The relative humidity was registered severe fluctuations in their values (from almost 40% to 65% and more) one every two weeks. Many studies described the preference of the olive fruit fly to the high humidity, above 50% [37,38,51–53], and the moderate temperature on the number of flies captures below than 25°C [32–35,37,38]. The rate of the infested fruits observed was significantly higher in the tree zones with 0-25% fruit load rate than that of the other tree zones.

These results highlighted the importance of the fruit load rate in relation to the OFF attack. Thus, the infested fruits were correlated as much with the fruit load rate or the size of the fruit as with the number of adults captures. Then our observations allow us to set an algorithm model for bait spraying intervention, when we have the first symptoms, taking into consideration the threshold of the BBCH equal at least 85%, that of the fruit load lesser than 25%, with an average of adult captures lesser than 5 adults by trap by 7 days.

5. Conclusions

These results obtained with conventional traps, georeferenced trees, and compiled parameters such as temperature, relative humidity, tree phenology, and fruit load rate, could be the database to an automated or semi-automated system based on electronic traps, then, to implement a decision support system, DSS, to help in decision making for managing *Bactrocera oleae*, and to reduce the frequency and the volume of insecticide.

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