# Integrated Pest Control for the Olive-Fruit Fly: Remote Pest Monitoring and Optimized Bait-Sprays

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**Abstract.** This paper demonstrates the application results of an integrated pest control framework for the olive-fruit fly [*Bactrocera oleae*, (Gmelin, Diptera: Tephritidae)]. The automation, optimization and thus finally the assurance of optimal pest management including both the remote insect's population monitoring and the controlled application of bait-sprays are presented. The proposed framework consists of a novel "smart" McPhail-type e-trap for remote monitoring the insect's population, a prototype gun sprayer providing precise adjustment and control of the sprayed quantity and full spacial and quantitative spray recording and a web-based application offering monitoring and real-time decision making for the surveillance authority. The results indicated its reliability, endurance and capability to provide on-time and reliable monitoring of the insect's population, optimal application of bait-sprays and rational use of insecticides. The proposed framework was found capable to minimize the dependence of the bait-system's effectiveness upon human intervention. The analysis of the produced olive oil indicated excellent qualitative characteristics.

**Keywords:** Pest control, bait-sprays, McPhail trap, *B. oleae*, olive-oil.

## 1 Introduction

Olive-fruit production is of crucial importance for olive growers all around the world. The olive-fruit fly [*Bactrocera oleae* (Gmelin) (Diptera: Tephritidae)] (Figure 1 on the left) is the main inimical pest of olive-tree cultivations worldwide. It causes both quantitative and qualitative damage to table olives and olive-oil production with enormous economic impact thus necessitating annual management. Yet, economic loss in Greece due to the fly is ranged from 30% up to 35% (Pavlidi et al., 2013) although control is almost universally applied.


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**Fig. 1.** The olive-fruit fly *Bactrocera oleae* (Gmelin) (Diptera: Tephritidae) (on the left) and a classic glass McPhail-type trap (on the right).

*B. oleae* control methods mainly include: cover sprays applied from the ground, sterile insect techniques, mass trapping, biological control and bait-sprays applied from the ground. The protein-based bait-spray method was mainly developed due to issues related with serious side effects on the environment and on human's health caused by cover sprays. The bait system is an Integrated Pest Management (IMP) method as it manages to reduce pesticide levels with simultaneous beneficial results for predators, parasitoids and pollinators (Varikou et al., 2016). With this method, only a small part of the tree's canopy is sprayed with the insecticide solution (approximately 300 cc/tree, one tree after another or even one row after another of the orchard).

As far as it concerns Greece, *B. oleae* control is centrally managed and funded by the Ministry of Rural Development and Food and Regionally/locally supervised by the Directorates of Agriculture and Veterinary, and includes both the monitoring of the insect's populations and the application of bait-sprays (only) from the ground. Its annual cost approaches twenty (20) million euros (Pavlidi et al., 2013; Varikou et al., 2016). However, despite the profound potential of the method, its application is characterized by a series of drawbacks and limitations, as it is practically unchanged for decades, without any adoption of technological solutions for its improvement. These limitations include, but are not limited, to the following:

- The insect's population monitoring frequency (every 5 or 7 days) is a rather expensive and frequently biased procedure,
- The sprayed quantity per tree is practically unknown due to the catholic use of conventional spraying equipment,
- Safety and health at work issues arise due to improper use of the conventional equipment and/or due to the use of improper equipment,
- Bait-sprays is not a certified procedure, thus its proper application is totally based upon the sprayer's experience, reliability and ethics,
- The actual monitoring of the whole process necessitates the use of specialized personnel and is currently applied by sampling,
- The sprayers generally cover large areas. Thus, it is difficult to memorize them and their borders. Their route is not recorded and/or monitored, often leading to large areas left without treatment.

Efforts to automate the process may be found in the literature. The use of GIS techniques for mapping olive fly populations – captured in glass-type McPhail traps – has been presented (Papafilippaki et al., 2007), applied in a manual manner though. Recently, an electronic McPhail trap – not tested in the field yet – was presented in (Potamitis et al., 2014). A novel web-based information system for monitoring the Bactrocera dorsalis population was proposed in (Jiang et al., 2012), but without accounting for pest control. A location aware (expert-base) system was proposed in (Pontikakos et al., 2012) and a sensor controlled sprayer was presented in (Chueca et al., 2008) for citrus orchards. Yet, the existing studies did not present any impacts on the final product.

This paper presents a novel prototype integrated system, which offers – for the first time – a complete and optimized pest management framework. It provides real-time remote monitoring of the insect's population, assists the expert entomologists to take on-time decisions concerning the application of sprays, and further pursues the sprayers to apply bait-sprays with an optimal manner. The core components of the system are:

1. A "smart" McPhail e-trap presented in (Doitsidis et al., 2017),
2. A gun sprayer enabling the application of very specific amount of spray solution at each single spray,
3. A device for fully recording the bait-spray procedure in terms of both space and quantity, and,
4. A novel web-based platform for mapping, remote monitoring and control of bait-sprays allowing real-time decision-making.

# 2 Methods and Materials

## 2.1 The "Smart" McPhail e-Trap

The "smart" McPhail e-trap consists of a proper modification of its conventional plastic counterpart. A dedicated embedded system providing automatic monitoring of *B. oleae* population in the field was developed. Further details regarding the electronic design, development and evaluation of the smart e-trap may be found in (Doitsidis et al., 2016). The main advantage of such an e-trap is the ability to provide unbiased and real-time remote monitoring the fly's adult population (through a series of captured pictures) at any desired frequency. Its final version – after a series of modifications and improvements – installed in the olive-grove and a sample photo of its interior are shown in Fig. 2.

## 2.2 The Automatic Spraying Subsystem

The proposed spraying device consists of an advanced extension of an ordinary spraying mechanism. A magnetic switch is installed beneath the trigger of a common spraying gun. An electromagnetic valve (solenoid) is installed at the tractor's pump output. After the solenoid and before the spraying gun, an extremely accurate AISI-

316 stainless-steel flow-meter sensor is installed. Its complete installation on a typical small-scale tractor used for bait-sprays – applied form the ground – in Crete, Greece, is shown in Fig. 3.

**Fig. 2.** The “smart” McPhail e-trap installed in the field and a picture of its interior.

**Fig. 3.** The developed spraying subsystem installed on a typical small-scale tractor.

### 2.3 The Recording Subsystem

The aim of the recording device is twofold: (a) To fully control the spraying duration by appropriately handling (open/close) the solenoid, thus precisely adjusting the spraying quantity and (b) to fully record both the tractor’s path and route within the olive grove and the sprayed quantity for each single spray. A dedicated embedded system was designed using a GPS module, a mosfet driving the solenoid, and a GSM module for real-time data transmission (see Fig. 4.). The tractor’s path and route (geographical position, and time) was recorded once a second ($f_s$ = 1 Hz) and at each single spray.

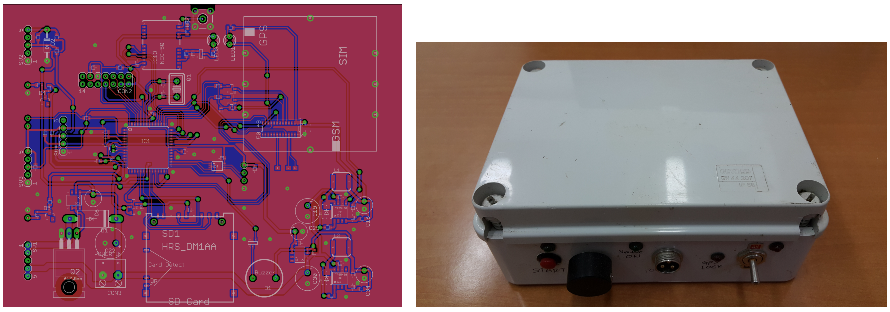


**Fig. 4.** The PCB layout of the recording subsystem (on the left) and its final implementation (on the right).

### 2.4 The Web-Based Platform

The aim of the developed web-based platform was to provide the ability of a complete representation of all the information, which are, images acquired by the McPhail traps, as well as spraying details (position, time, sprayed quantity). For this purpose, a suitable information system was developed witch may be accessed at: http://edakos.chania.teicrete.gr. Its usage may significantly facilitate the work of specialized agriculturists as they can easily monitor the insect's population evolution via "smart" e-traps in an unbiased way, being proactive and thus on-time order bait-sprays when required (see Fig. 5). Additionally, they can monitor the tractor's route within the olive-grove and control its potential coverage during the spraying procedure (see Fig. 6).

### 2.5 System Evaluation Under Field Conditions

**Experimental Area**

A large-scale field trial was conducted on the island of Crete, Greece, in olive-groves (cv. Koroneiki with small fruit, an oil-producing olive variety) of Vasilopoulo village during the summer of 2015. The olive trees of the orchard were not irrigated and were 30-50 years old, 5-7 m tall and 6-7 m apart from each other. The tree density at the time of the study was approximately 200 trees/ha, and the orchard consisted of (approximately) 8,000 olive trees. The mean olive-fruit production per tree was estimated at approximately 70% of the normal yield (approximately 60-70 kg/tree) in 2015, see Fig. 7.

**Evaluation of the Automated Trap**

The proposed Autonomous e-Trap (AT) was evaluated for its effectiveness in monitoring the olive-fruit fly (adult) populations. It was also compared with the yellow Plastic-type Trap (PT). The typical Glass-type McPhail Trap (GT) was also used as a reference trap. Further details may be found in (Doitsidis et al., 2017).

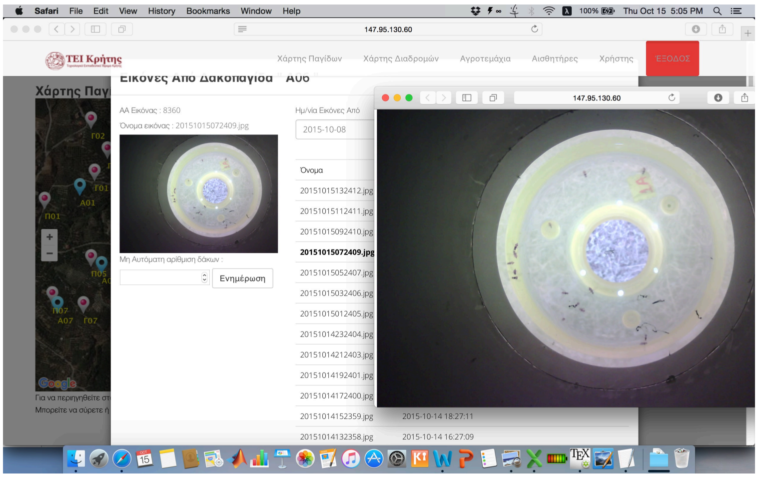

**Fig. 5.** The trap's web interface.

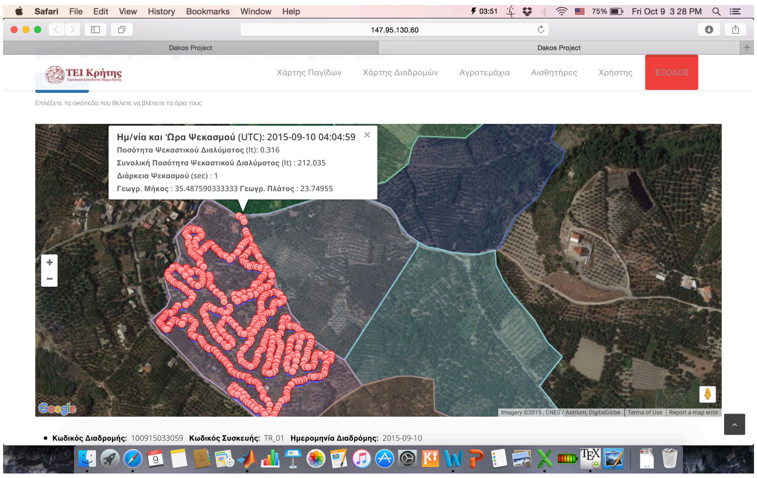

**Fig. 6.** Bait-spray details such as geographical position, time-instant, single and total sprayed quantity, represented on properly modified digital maps.

### Evaluation of the Spraying System

Bait-sprays were implemented after considering the olive fly population density and distribution and the alive and total fruit infestation levels. The total number of bait-spray applications for achieving an acceptable crop-protection level throughout the summer period was also considered, following the EPPO (2012) standards.

### Design and Layout of the Experiment Field

The experimental design used in the present study consisted of a randomized block with two treatments and four replicates, resulting to a total of 8 sectors during 2015. Each sector comprised of approximately 1,000 trees, see Fig. 7.

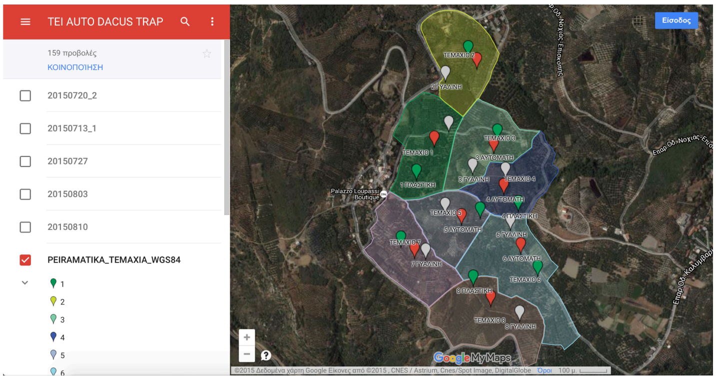


**Fig. 7.** The test olive-grove comprised by eight (8) sectors with their boundaries also depicted.

### Insecticides

A hydrolysed protein (2%) was mixed with the registered insecticide in tractor containers (500 lt) for the implementation of bait-sprays. The liquid hydrolysed protein was 75% ("prot"; Entomela 75SL, 25% w/w urea and its conciseness percentage was equal to 75% w/w; Stavrakis Company, Greece). The tested phytosanitary product was thiacloprid + deltamethrin ("th+dlt"; class: Neonicotinoid and pyrethroid; Proteus 110 OD; 300 ml/hl; Bayer CropScience AG). The selected insecticide solution quantity (300 ml/tree) and the way of its application followed the EPPO (2012) standards.

### Timing of Bait-Spray Applications

The total number of bait sprays and their timing were scheduled based on the captured olive flies following both the numerical threshold of 5 flies/trap/week and the prevailing climatological conditions within each experimental sector. Bait-sprays were applied only when the temperature and the wind velocity were both lower than 28$^{o}$C and 5 bf (or equivalently 20-28 km/h or 5.5-7.7 m/s), respectively.

The proposed practice of "Automatic" Bait Sprays (ABS) was compared to the Conventional practice of Bait Sprays (CBS, using conventional equipment). An interval of approximately 14 days with no spraying activity between two successive applications has been held, as indicated by the insecticide's regulations. Sprays were applied very early in the morning. Sprays stopped about a month before harvesting time, which for the Koroneiki variety is the end of October (Table 1).

### Olive-Fruit Infestation Estimation

To estimate the olive-fruit infestation level, which is expressed as infestation (live eggs, L1, L2, L3, pupae and exit holes) and total infestation (live and dead eggs; L1, L2, L3; pupae), fruit sampling was carried out twice per month from August till October 2015. The acceptable empirical infestation threshold was set to 8-10% for the variety of Koroneiki.

**Olive-Oil's Qualitative Evaluation**

To evaluate the qualitative characteristics of the produced olive-oil, 5 kg of olive-fruits from each experimental sector were randomly collected by hand, during harvesting period (a specific date of November 2015). The collected fruits were then immediately transported to the Laboratory of Food Technology of the IOSV. Olive-oil was extracted at the same day using a laboratory scale olive mill (Callis Company). A number of qualitative characteristics have been evaluated including: (a) Free Fatty Acids (FFA) expressed as oleic acid, (b) peroxide value measured in milliequivalents of active oxygen per kg of olive-oil, (c) the coefficients of specific extinction at 232 and 270 nm ($K232$ and $K270$), (d) the variation of the specific extinction ($\Delta K$), (e) the fatty acid composition, and (f) the oil content in dry olive paste according to EC Regulation 2568. Polyphenols were also determined as the total polyphenols evaluated by the colorimetric method using Folin-Ciocalteu reagent as described in (Gutfinger 1981) with a UV spectrophotometer at 725 nm.

**Table 1.** Treatments, testing periods and dates of bait-sprays applications during 2015.

| | Bait Spray # | 1st 15/Jul | 2nd 11/Aug | 3rd 27/Aug | 4th 9/Sep | 5th 27/Sep |
|---|---|---|---|---|---|---|
| Test | Sector | | | | | |
| ABS | 1 | th+dlt | th+dlt | th+dlt | | th+dlt |
| | 4 | th+dlt | th+dlt | th+dlt | th+dlt | th+dlt |
| | 6 | th+dlt | th+dlt | th+dlt | | th+dlt |
| | 7 | th+dlt | th+dlt | th+dlt | th+dlt | th+dlt |
| CBS | 2 | th+dlt | th+dlt | th+dlt | th+dlt | th+dlt |
| | 3 | th+dlt | th+dlt | th+dlt | th+dlt | th+dlt |
| | 5 | th+dlt | th+dlt | th+dlt | | th+dlt |
| | 8 | th+dlt | th+dlt | th+dlt | th+dlt | th+dlt |

Spraying solution of protein 75% plus thiacloprid+deltamethrin "th+dlt", ABS: Automatic Bait-Spray
CBS: Conventional Bait-Spray

**Analysis of the Olive-Oil's Residues**

Pesticide residues of deltamethin were determined in the olive-oil's samples according to the AOAC Official Method 2007.01, using Liquid–Liquid Extraction (LLE) followed by dispersive Solid Phase Extraction (dSPE) (QuEChERS technique) with the use of Gas Chromatography with Electron Capture Detector (GC-ECD).

**Meteorological Data**

A number of meteorological parameters such as: mean daily temperature, relative humidity, wind speed and precipitation were recorded on the day of each spray application. The data were acquired using the weather station of the IOSV, which was located close to the experimental olive-grove.

**Data Analysis**

The number of adult olive-fruit flies (*B. oleae*) captured in all-types of McPhail traps, the number of olive fly individuals recorded in the olive samples, the qualitative parameter values and of the chemical residues were analyzed separately using one-way ANOVA. The mean values were separated using Tukey's honestly significant difference (HSD) test. Data analysis was conducted using the statistical package JMP (SAS Institute, 2008). The mean values were considered to be significantly different at the 5% level ($P < 0.05$).

# 3 Results and Discussion

## 3.1 Evaluation of the Autonomous McPhail Trap

The monitoring of the olive-fruit fly population was implemented by three different type of McPhail traps, i.e. the classical Glass-Type (GT), the yellow Plastic-type (PT) and the proposed Autonomous Trap (AT), for comparison purposes. The number of captured flies within the AT and GT traps were found significantly lower than that of their PT counterparts. Nevertheless, there was not found a significant – from a stati-stical viewpoint – difference between the AT and the GT traps (Doitsidis et al., 2016).

## 3.2 Evaluation of the Automated Spraying System

The results of the present study indicated that the Automated Bait-spray System (ABS) was as effective as the Conventional Bait-spray System (CBS). It is important to be stated that the tractor's driver and the sprayer who implemented all the sprays, were particularly experienced and reliable, thus ensuring that even the conventional bait-sprays were performed following the protocol at a maximum point. The two spraying systems (Automated and Conventional) were compared in terms of olive-fruit fly population, infestation and total number of bait-sprays applied in all experimental sectors treated by either method. The captured flies/week/trap and the recorded infestation level were found not to significantly differ from each other (Fig. 7 and Table 2, respectively).

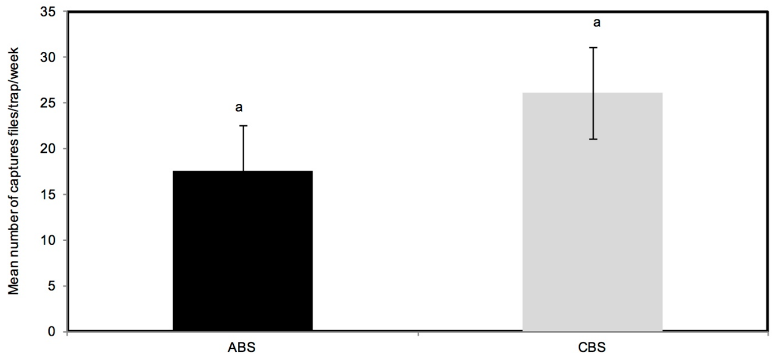


**Fig. 8.** Mean number of captured adult flies per trap and week for each applied spraying method during 2015. Bars with the same letter are not significantly different at $P < 0.05$. ABS: Automatic Bait-Spray; CBS: Conventional Bait-Spray.

### 3.3 Analysis of the Produced Olive-Oil

Olive-oil tests were performed to samples acquired from all sectors for both treatments. The tests were performed according to quality indices of free fatty acids, peroxide, etc. All samples were classified as extra virgin oil according to the International Olive Oil Council (IOOC, 2001).

Insecticide residues on olive-oil were also examined and they were found extremely low for all active ingredients and not significantly different between treatments (Table 3). No significant differences were detected among the samples obtained by the two applied treatments (ABS and CBS). The results of this study indicated that the active ingredients applied by either automatic or the conventional sprays, were not transferred into the produced olive-oil.

**Table 2.** Fruit infestation for each treatment during 2015. For each type of infestation (alive, total), percentages followed by the same letter are not significantly different at $P < 0.05$. Alive: Alive infestation, Total: Total infestation.

| Date | 3/Aug/2015 | | 24/Aug/2015 | | 7/Sep/2015 | |
|---|---|---|---|---|---|---|
| | Alive | Total | Alive | Total | Alive | Total |
| ABS | 0.30±0.13a | 4.10±1.96a | 0.00±0.00a | 2.30±0.88a | 0.35±0.10a | 8.40±1.24a |
| CBS | 1.25±0.81a | 9.35±4.43a | 0.15±0.15a | 7.05±2.09a | 0.35±0.24a | 9.65±4.93a |
| Date | 21/Sep/2015 | | 5/Oct/2015 | | | |
| | Alive | Total | Alive | Total | | |
| | 0.35±0.12a | 6.70±1.34a | 0.25±0.19a | 3.30±0.30a | | |
| | 0.33±0.16a | 5.85±1.24a | 0.38±0.28a | 4.43±2.35a | | |

ABS: Automatic Bait-Spray, CBS: Conventional Bait-Spray

### 3.4 Discussion and Future Work

Despite the obvious and pronounced benefits gained by the potential introduction of modern ICT's, olive-fruit fly control in Greece is practically unchanged during the past decades without adopting new technological solutions. The experience gained thus far clearly shows that the method's efficiency and success highly depend upon human intervention, i.e. by the people who apply and monitor the process.

The main objective of this study was to explore the effectiveness of introducing technological solutions in a way to assist the people who involve with the olive-fruit fly control, to apply both the population monitoring and the application of bait-sprays in an optimal manner within the "sense-act-monitor" framework, thus minimizing the dependence of its success on human intervention. By introducing modern ICT technologies, all the acquired information including adult fly captures and spraying data, were remotely and securely transferred to the main computer and via a suitably designed user-friendly web-based platform, they were provided to the authorized personnel using properly modified digital maps, for on-time, accurate and reliable decision making.

Despite the fact that both the spraying systems (automatic and conventional) were proven to provide equivalent efficiency, it should be stated that the ABS can ensure and guarantee that bait-sprays will be implemented with an optimal manner. The new spraying device was found to be reliable, robust, and not complex in terms of technological equipment thus offering tremendous ease of use, providing the possibility to any potential sprayer to spray in an optimal way. Further improvements may include the addition of extra sensors for continuous monitoring outside temperature and wind velocity during the spray process and a fast focus camera for picturing the specific tree's canopy part being sprayed.

The web-based platform was also proved to be a powerful tool for the supervising authority and its personnel. For the first time, all the necessary information – trap's captures and spraying data – were all collected in an unbiased manner and subsequently depicted on digital maps offering the possibility for real-time monitoring and decision making. The deployment of extra sensors in the field and the development of the necessary (desktop and/or mobile) applications, for providing targeted information to various groups regarding the prevailing conditions in the cultivation, available agricultural practices and necessary actions have been also considered as future actions and improvements of the system.

**Table 3.** Mean values for various olive-oil qualitative parameters and insecticide residues.

| | ABS | CBS |
|---|---|---|
| Free fatty acids (% w.w. oleic acid) | 0.31 a | 0.21 a |
| Peroxide (% meq O2/kg) | 5.73 a | 5.35 a |
| *K*232 | 1.61 a | 1.49 a |
| *K*270 | 0.17 a | 0.15 a |
| Phenols (mg/kg expr. gallic acid) | 446.48 a | 421.10 a |
| Thiacloprid residues (mg/kg)<br>(Report limit: 0.01 mg/kg) | 0.0168 a | 0.0160 a |
| Deltamethrin residues (mg/kg)<br>(Report limit: 0.01 mg/kg) | 0.0087 a | 0.0072 a |

## 4 Conclusions

In this study, the results of the design, development and evaluation of technological solutions for the optimization of pest control for the olive-fruit fly were presented. A holistic precision agriculture framework comprising a complete Integrated Pest Management system was presented for the first time. The proposed IPM system was tested in a large-scale experimental olive-grove and the results, though at a relatively preliminary stage were found to be encouraging and promising. The study indicated the system's potential to minimize the dependence of the bait-system's effectiveness upon human's intervention. Its main benefits are the increased environmental protection through the rational use of insecticides and the improvements of human's health and safety at work by reducing laborious and tedious tasks.

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## References

1. Chueca, P, Garcera, C., Molto, E. and Gutierrez, A. (2008) Development of a sensor-controlled sprayer for applying low-volume bait treatments. Crop Protection, 27, p.1373-1379.
2. Doitsidis, L., Fouskitakis, G., Varikou, K., Rigakis, I., Chatzichristofis, S., Papafilippaki, A. and Birouraki A. (2017) Remote monitoring of the Bactrocera oleae (Gmelin) (Diptera: Tephritidae) population using an automated McPhail trap. Computers and Electronics in Agriculture, 137 p.69–78.
3. EPPO (2012). Efficacy evaluation of insecticides, Bactrocera oleae-bait application. Bulletin OEPP/EPPO 42, p.431-433.
4. Jiang, J., Lin, T., Yang, E., Tseng C., Chen C., Yen C., Zheng X., Liu C., Liu R., Chen Y., Chang W. and Chuang C. (2012) Application of a web-based remote agro- ecological monitoring system for observing spatial distribution and dynamics of Bactrocera dorsalis in fruit orchards. Precision Agriculture, 14, p.323-342.
5. Papafilippaki, A., Nikiforakis, K. and Stavroulakis, G. (2007) Optimization of the dacus olea control (Bactrocera oleae) with the use of GIS. Proceedings of the 12th Panhellenic Conference of Endomology, p.321-327.
6. Pavlidi, E., Yusupova, A., Paya, I., Peel, D., Martinez-Garcia, E., Mack, A. and Grossman, V. (2013) Monitoring housing markets for episodes of exuberance: an application of the Phillips et al. (2012, 2013) GSADF test on the Dallas Fed

International House Price Database. Federal Reserve Bank of Dallas Globalization and Monetary Policy Institute, Working Paper, 165.

7. Pontikakos, C., Tsiligiridis, T., Yialouris C. and Kontodimas D. (2012) Pest mana-gement control of olive fruit fly (Bactrocera oleae) based on a location-aware agro-environmental system. *Computers and Electronics in Agriculture*, 87, p.39-50.
8. Potamitis, I., Rigakis, H. and Fysarakis, K. (2014) The Electronic McPhail Trap. Sensors, 14, p.22285-22299.
9. Varikou, K., Garantonakis, N., Birouraki, A., Ioannou, A. and Kapogia, E. (2016) Improvement of bait sprays for the control of Bactrocera oleae (Diptera: Tephritidae). Crop Protection, 81, p.1-8.