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Assessment of IPM using Conetrap®, Magnet™MED and Moskisan® attract-and-kill and mass-trapping devices to control *Ceratitis capitata* (Diptera: Tephritidae) in citrus orchards

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Abstract
The aim of present study was to test Cone Trap®compared to Moskisan® baited with Biolure® and Magnet™MED. Two trials were conducted on summer fruits to assess capture performances and selectivity of the ConeTrap® and on citrus to evaluate its effectiveness in Citrus protection. The Medfly'scaptures were 5 to 10 times higher with ConeTrap® than Moskisan® and it was more selective to non-target arthropods with an average of 6.3% against 19.05% for the Moskisan®. On citrus, the ConeTrap® as well the other systems were as effective to reduce Medfly level and damage compared to the control. The ConeTrap® has shown its efficiency in Medfly captures and fruit protection with less than 1% of damaged oranges. Furthermore its recommended density per ha could be reduced it is hence an interesting system for the Medfly mass trapping.

Keywords: Medfly, ConeTrap®, Moskisan®, Magnet™MED, Citrus

1. Introduction
As in other Mediterranean countries [1,2, 3], in Tunisia several studies demonstrated that mass trapping inserted in an IPM program is effective to control the Medfly in citrus orchards [4, 5, 6, 7]. These last years, actually since 2010, an effort has been deployed by the Ministry of Agriculture to transfer these technologies to farmers with the aim to replace chemicals and especially the malathion sprays by more environmentally friendly control methods. However the adoption of IPM based on mass trapping by the farmers is still low, around 10% according to a recent survey achieved in Takelsa, the first region where farmers received mass trapping subsidized equipment (traps and attractants). According to farmers, among the constraints for sustainable adoption of IPM, is their lack of information and support by administration staff but also the high cost of the traps and baits [8].
Currently in Tunisia there are a few mass trapping systems registered and marketed. In order to expand the range of devices available for farmers to match their financial capacities, others have to be tested and registered. This was the objective of present study to compare 3 mass trapping systems to control the Medfly in citrus. This study's particular goal was to test the ConeTrap® system, a new trap that is funnel-shaped, very light, and can be folded.

2. Materials and Methods
2.1 Study sites
Two locations were considered for the present study: the first is RafRaf where a preliminary trial was conducted on summer fruits to assess the capture performances of ConeTrap®. The second essay was carried out in the region of Mornag on citrus to evaluate ConeTrap® efficiency compared to other already known devices.

2.2 Summer fruits trial
The trial on summer fruits was conducted in RafRaf, a coastal region located about 50 kms North of Tunis, where are grown mostly summer fruits such loquats, apricots, peaches, figs, apples, pears and some citrus. Because of the mild climate of RafRaf, the Medfly populations reach regularly very high levels during July and August. This region was chosen to do the preliminary tests of capture performances and selectivity of ConeTrap®. The trial was implemented in a private orchard of about 2000 m^2 where are grown various summer fruit

trees: an apricot tree local variety "El euch", 3 fig trees, 3 apple trees variety "Golden", 2 loquat trees, 2 olive trees, 2 peach trees, 2 pistachios (Fig. 1).

On May 22th, 2014, eight ConeTrap®traps baited with dry attractant in a single package and eight Moskisan® traps baited with Biolure® and filled with water were hung on trees alternating between the 2 types of traps to compare both trap performances. Every week, from May 29th until July 31th 2014, the arthropods captured by each trap were removed and conserved in an individual vial filled with alcohol 70%. For Moskisan® traps every week we had to add water in order to maintain enough liquid until the next survey. After that, each trap was moved in a clockwise direction to take the place of the next one. This is to avoid the host plant or location effect, such ant attacks against captures. By doing so, each trap did a complete tour of all the host plants to finally return back to its initial position (Fig.1).

In the lab for each sample (16/ week and 160 in total) the arthropods captured were separated in Medfly (males and females) and non-target arthropods (NTA), and then counted. For each trap and date we could calculate the total of Medfly captured the % of Medfly females and the % of NTA.

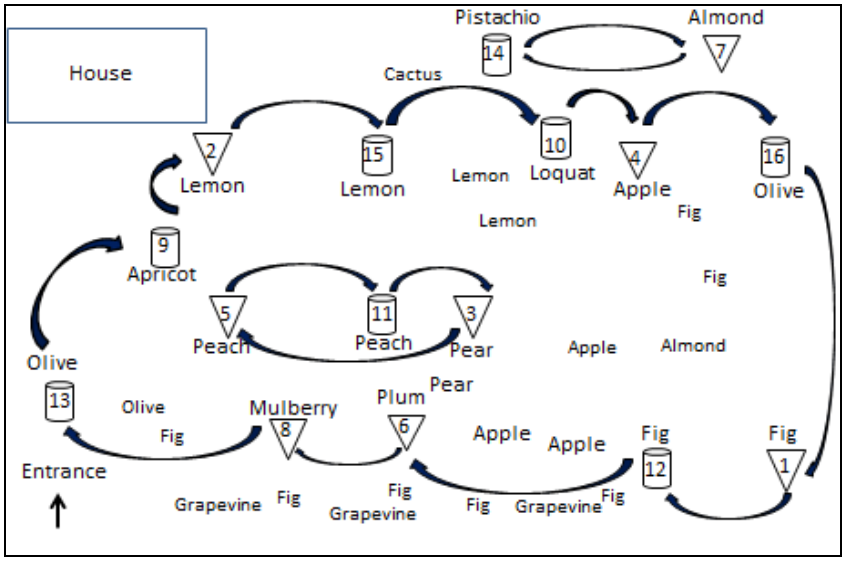

Fig 1: Location of traps on fruit trees on July 11th 2014 after clockwise rotation

Cone Trap ▽ Moskisan ⬭

2.3 Citrus trial

After testing the Cone Trap® on summer fruits it seemed that this system has fairly good capture performances and selectivity of Medfly. Thus we decided to try it in citrus orchard. The study was conducted in 2 citrus orchards located in Mornag, 15 kms from Tunis in the North. The 2 orchards were situated some 2 kms from one another in the communities of Sidi Saad and Ouzra, making possible to consider them as 2 replicates. Both orchards included many citrus varieties, but the trials were implemented on Navel oranges, because of its sensitivity to Medfly attack.

2.4 Applied IPM programs

In both orchards the same IPM programs were implemented from September 8th, 2014 to January 6th 2015. The IPM programs combined the monitoring of Medfly level and 3 control measures: mass trapping or attract and kill + sanitation + spinosad bait sprays.

2.4.1Mass trapping or attract and kill

For mass trapping, the systems tested were Moskisan® and Conetrap®. The Moskisan® (SansanProdesing) baited with Biolure®Unipack (Suterra) well known by the farmers, has already proved its efficiency at 40 traps/Ha to control the Medfly when inserted in an IPM strategy. The ConeTrap® (Probodelt) baited with a dry food attractant is a new system, not registered in Tunisia. The traps have a yellow conical base with 4 entry holes and a clear lid impregnated with cypermethrin. The new feature of this folding trap is that it is sold unassembled but it's very easy to assemble. The bait is composed by ammonium acetate, trimethyl amine and alkaline diamine and is formulated in a single diffuser to place directly inside the trap. This bait as well as the Biolure® Unipack (Suterra) has a persistence of 120 days.

The attract and kill device used was the Magnet ™ MED (Suterra) which has been already registered in Tunisia. This system consists of a plastic white device impregnated with deltamethrin, and containing Biolure® Unipack (Suterra). The attractant is released through numerous horizontal slots located in both sides of the device that makes it acting as a controlled mechanism for at least 180 days. The Magnet ™ MED device was used according to the recommended density to control the Medfly in citrus: 50 units/Ha.

2.4.2 Sanitation

This measure consists in removing the punctured fallen fruits once a week.

2.4.3 Spinosad bait sprays

Four spinosad treatments were applied on October 10th, 24th, and 31th and on November 18th, according to the threshold of 0.5-1 Medfly/trap/day. The spinosad (Success Appât) was sprayed by a backpack sprayer at 1L/Ha (1:10), over one row out of 3 rows.

In both orchards, four plots were chosen for the four treatments: IPM with Moskisan ®, IPM with Cone Trap®, IPM with Magnet ™ MED and Control without any control measure. The number of different traps deployed as well as the attract and kill units were adjusted according to area of each plot.

2.5 Medfly monitoring
From the start of the study, the Medfly level was monitored weekly by Moskisan ® traps baited by Biolure ®. Two traps were hung in each plot in both orchards. So a total of 8 Moskisan ® traps were checked weekly in both orchards.

2.6 Parameters checked
To assess the effectiveness of the applied programs, 2 parameters have been checked: the Medfly level expressed by the average number of Medfly/trap/day (MeTD) and the percentage of punctured fruits. The MeTD is equal to the mean of the number of Medflies captured by the 2 Moskisan® traps per plot that was counted every week.
The percentage of punctured fruits was estimated on October 21th approximately at the color-break and on December 23th 2014 at the full fruit maturity. In each plot, four trees were chosen and 60 fruits/tree were checked for the punctures. The punctured oranges (%) is calculated by (the number of punctured oranges/240) x 100. At the harvest the number of oranges checked/plot was doubled.

2.7 Statistical analysis
To assess the effectiveness of IPM programs to reduce the Medfly level and to protect the fruits, a proc mixed of SAS was performed by the SAS software (version 9.1). To check if the results were significantly different between the treatments (3 IPM programs and Control), the MeTD and the percentage of punctured fruits were analyzed statistically using the LS mean. All data related to the 4 months of the study were analyzed.

3. Results
3.1 Capture performances and selectivity of ConeTrap® on summer fruits
The total Medflies captured by ConeTrap® were significantly higher than by Moskisan®, 23874 and 4724 respectively. Especially in July, the number of Medflies caught in ConeTrap® reached 5 to 10 times more than in Moskisan® with a maximum of 6545 Medflies/8 traps/week that means around 117 MeTD which represents a great density (Fig. 2).

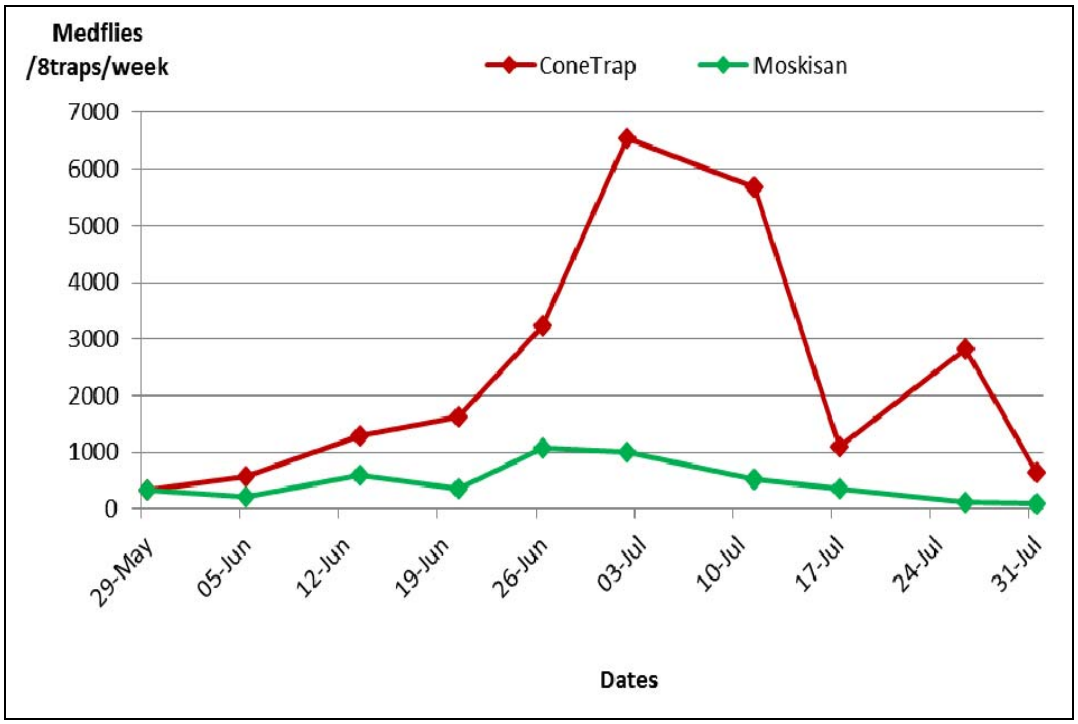

Fig 2: Medflies captured by ConeTrap® and Moskisan® systems from May 29thtoJuly 31th 2014 on summer fruits in RafRaf (North of Tunisia).

Regarding the selectivity to female Medfly, both systems captured a high percentage of females, with 10% more for Moskisan® which caught 83% of females (Table 1).
But if we consider the selectivity to NTA, ConeTrap® is 3 times more specific to Medfly with an average of 6.3 and 19.05% NTA respectively over the total duration of the survey. For Moskisan® the NTA rate get higher to reach a maximum in early July when the Medfly density was the highest. But for ConeTrap® the dynamic of NTA rate was not similar as it shows its highest values in June and from July the NTA rate remained very low while the Medfly was captured in very high numbers (Fig. 3).

Table 1: Selectivity to females of Medfly and NTA for Cone Trap® and Moskisan® systems based on 10 weeks of captures (May 29th- July 31th 2014).

Trapping systems	Selectivity to Medfly females and NTA				
	Total Medflies	Total Medfly Females	Total NTA	% of Medfly females	% of NTA
ConeTrap®	23874	17294	1601	72.44	6.28
Moskisan®	4724	3910	1112	82.77	19.05

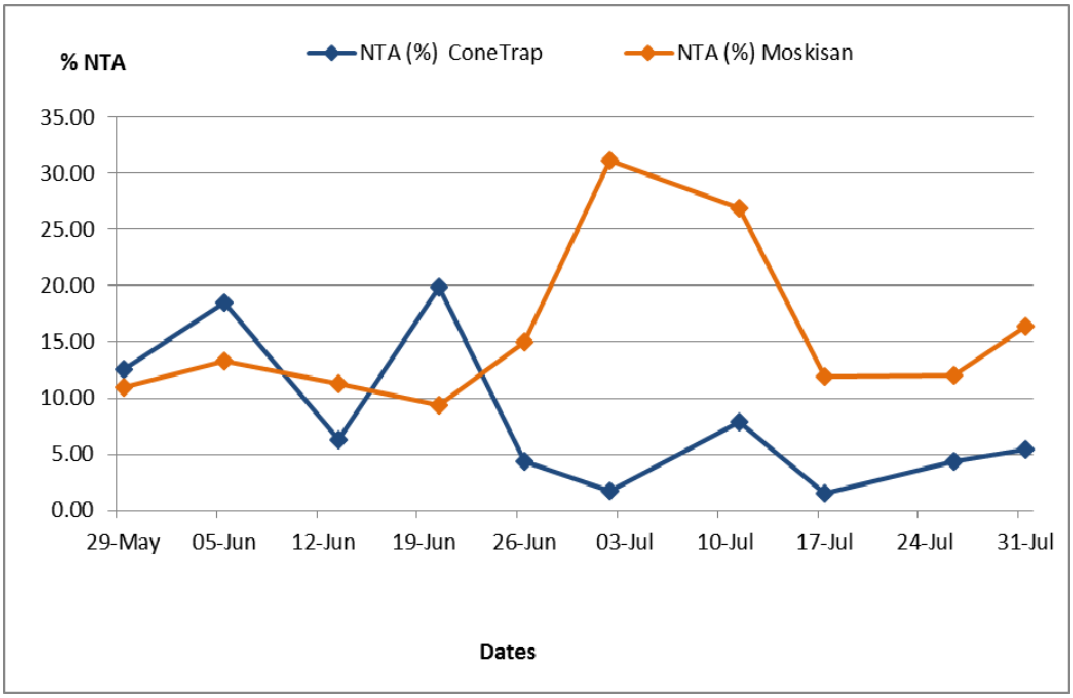

Fig 3: Non-target arthropods captured besides Medfly by Cone Trap® and Moskisan® systems from May 29th to July 31th 2014 on summer fruits in Raf Raf (North of Tunisia).

3.2 Effectiveness in citrus fruit protection

3.2.1 Effect on the Medfly level

First 2 remarks must be pointed out:

- We will consider only the results obtained in one orchard (SidiSaad) because in the second (Ouzra), the plot chosen as the Control did not "behave" as such probably because of its situation between the 2 mass trapping plots with Moskisan® and ConeTrap® systems. The Control plot likely took benefit of the mass trapping to the extent that the Medfly level there was lower than in all the treated plots. The Medfly level of the season 2014-15 was low compared to previous years. For instance it was 4 times lower than in 2011-12.

The Medfly level (MeTD) was significantly lower in the 3 treated plots than in the control especially from early November until the first decade of December (Fig.4).

The average MeTD over the entire study period did not exceed 1 for all the systems, with about 0.4 for Moskisan® and ConeTrap® and the double for the Magnet™MED without significant difference (Table 2). So the 3 systems were as effective to reduce the Medfly level significantly to control ($F = 38.18$;ddl = 36 ; $p<0.0001$).

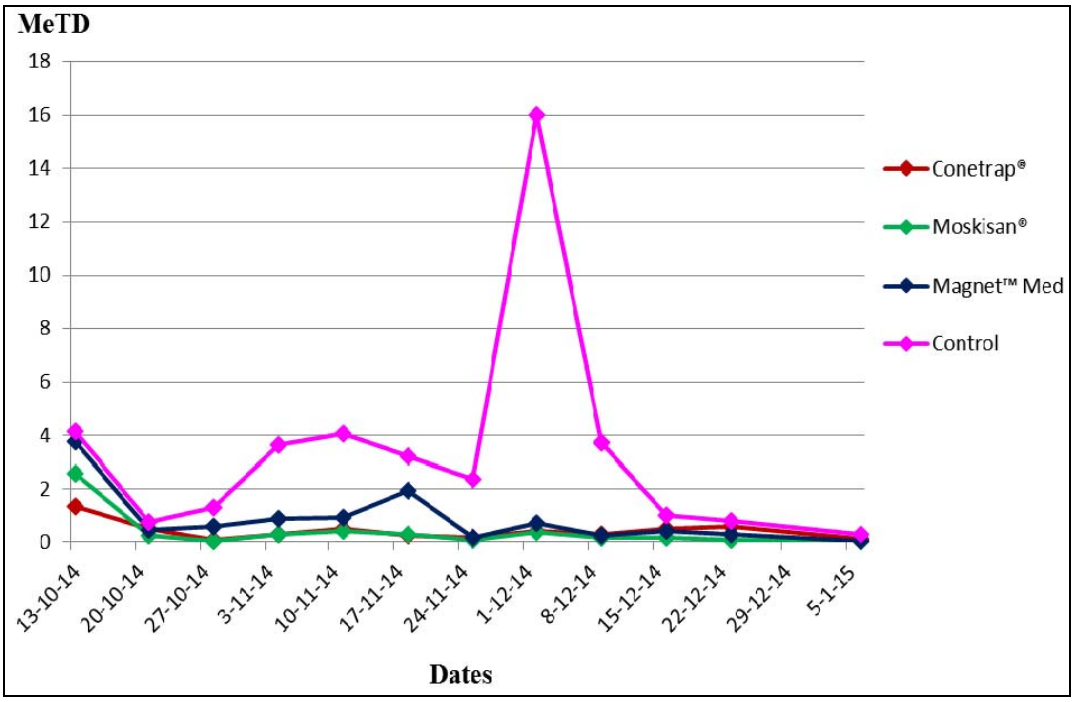

Fig 4: Captures of Medflies by Moskisan® traps in the different treatments on oranges Navel (Mornag, Sidi-Saad). MeTD is the number of Medflies per trap per day.

Table 2: Average number of MeTD for the entire study period for the different treatments (Mornag, Sidi-Saad).

Treatments	Moskisan®	Cone Trap®	Magnet ™ MED	Control
Average MeTD	0.33 ± 0.23 b	0.38 ± 0.23 b	0.76 ± 0.23 b	3.19 0.23 a

3.2.2 Effect on the harvest protection

The mass trapping deployed with Moskisan® traps completely saved the oranges until the harvest (Table 3). This result was comparable to that obtained by ConeTrap® with less than 1% of damaged oranges. Until the third week of October the ConeTrap® system protected 100% of the oranges. The Magnet™MED also was effective to protect the fruits, with less than 3% punctured fruits. But both ConeTrap® and Magnet™MED systems were not significantly different from the Control (F = 2.23; ddl = 3; p = 0.1202). That could be explained by the low damage comparatively to other years where the percentage of damaged fruits in the Control, reached approximately 20%.

Table 3: Comparison of IPM programs with Moskisan®, Conetrap® and Magnet ™ MED on fruit protection.

Dates	Punctured fruits per treatment (%)			
	Moskisan®	Cone Trap®	Magnet ™ MED	Control
21/10/2014	0 ± 1.72 b	0 ± 1.72 b	2.91 ± 1.72 ab	1.66 ± 1.72 ab
23/12/2014 (harvest)	0 ± 1.72 b	0.41 ± 1.72 ab	2.7 ± 1.72 ab	5.41 ± 1.72 a

4. Discussion

In Tunisia although it was not easy and took several years to substitute chemicals by alternative methods to control the Mediterranean fruit fly on citrus, it seems that IPM adoption is on the right track. A recent survey showed that the farmers are more interested in IPM than previous years but still have some difficulties to implement correctly the IPM components advised by the Ministry of Agriculture staff, which is mass trapping, sanitation, and monitoring population to decide for sprays. According to farmers, the main constraints were a lack of support and extension services to help solving daily issues relating to IPM components, the cost of traps and attractants, their addiction to pesticides, making the real adoption of IPM concerned only 10% of the producers [8].

So there is a need for expanding the supply of mass trapping devices that economically match the financial capacities of tunisian farmers. The objective of this study was to evaluate the ConeTrap®device, a new candidate for mass trapping use in citrus orchards.It is composed by a folding conical trap which lid is impregnated by Deltamethrin with dry bait in a single dispenser. The combination trap and lure is very cheap compared to the available models in Tunisia [9]. So we assess the Medfly capture performances, selectivity to non-target arthropods and efficacy in citrus fruit protection of the ConeTrap® compared to Moskisan® the most common and widely used trap in Tunisia, and to Magnet ™ MED which is a registered and available device in Tunisia.

The results obtained from this study showed that Cone Trap® was the number one for its Medfly capture performances, and selectivity to non-target arthropods as seen on summer fruits. This trap could capture almost 120 Medflies per trap in one day which is around 5-10 times more than Moskisan® although this latter was filled by water that is supposed to increase the retention of flies inside the traps. Lasa et *al.* [10, 11] in fact reported that for the Mexican fruit fly *Anastrephaludens,* Cone Trap® was not as effective because of its poor retention capacity allowing more than 50% of flies to escape after 30 min-observational period. Also, in another work Lasa and Cruz [11] reported that Cone Trap® was among 12 trap designs, intermediate in capturing another pest of mangoes, *A. obliqua* when baited with Hydrolyzed protein. This leads to suggestion that the capture performance showed by Cone Trap® in present study trial could be attributed more to its dry attractant than to the combination trap-attractant. This issue needs to be tested with both traps Cone Trap® and Moskisan® baited by Cone Trap®'s dry attractant. Especially that the combination Cone Trap®-Biolure had low *A. ludens* captures and high lacewings captures, around 1.2/ trap/day showing the worst selectivity compared to other traps with liquid baits [11].

In the other hand, the Cone Trap® dry bait is very convenient because it resists to tunisian summer conditions with very high temperatures often ≥ 40°C and low HR. The present study observed few weeks after trap installation that the powder liquefies but remains attractive. Liquids in general highly evaporate in few days, thus implicating servicing the traps regularly to restore the initial volume.

Besides, in the present study trial the Cone Trap® captured a very low percentage of non-target arthropods, that didn't exceed 10%. This can be considered as a very good selectivity because Raf Raf biotope is not chemically sprayed and known for its rich biodiversity especially during summers that are very favourable to insect outbreaks. This high selectivity could be attributed to Cone Trap® bait that seems to be more selective than Biolure.

In addition both devices trapped rather similar percentages of Medfly females more than 70% which is a very high specificity to females (72.5 and 83% respectively for ConeTrap® and Moskisan®respectively). This feature is very important for mass trapping because the *C. capitata* females, causing the damage, are the first target of this control method.

Considering the above, confirming the great attractiveness of the ConeTrap®(trap and lure), this device should be a promising tool for Medfly mass-trapping on citrus. That was the second goal of our study. When installed in citrus orchard combined with sanitation and spinosad sprays the ConeTrap® protected the harvest from Medfly stings without significant difference than Moskisan® and Magnet™MED. However, Moskisan® which is the most used device by the Citrus growers in Tunisia allowed the best protection with no damage at the harvest. This work confirmed again the power of mass trapping based IPM to control Medfly as in other Mediterranean countries on different varieties of citrus [12-14].

It also demonstrated that the lure and kill device Magnet ™ MED has the same efficiency than mass trapping when included in an IPM program. This result was already found by Navarro-Llopis *et al.* [14] who obtained a similar efficacy between Magnet ™ MED, mass trapping and spinosad® weekly sprays to reduce Medfly level under the economic threshold. According to Navarro-Llopis *et al.* [14], the Magnet ™ MED device is more advantageous than mass trapping strategy even they are based on the same attractant (Biolure)

which action duration is almost 6 months. He argued that Magnet ™ MED is easier to handle, takes less time to deploy on the trees, doesn't need to be serviced and is economically reasonable for farmers. More recently, Navarro-Llopis *et al*.[15], demonstrated that trees with attract and kill devices, showed less damage than those with traps that have at least the same damage than trees without. For these authors some traps and baits can make the fruits more susceptible to Medfly punctures. This issue needs to be precised for various traps and attractants, especially for Biolure that is the most used bait in Tunisia. In Tunisia farmers seem to prefer traps because there is a psychological effect that makes farmers more confident to traps because they can see the result of trapping which is the amount of flies caught inside the traps. Moreover the traps can be reused several years if they are washed and stored which is not the case for the Magnet™MED. Nevertheless both strategies showed a good efficacy in our work, but because of the 4 times lower Medfly level and damage compared to the previous years, this situation didn't allow to show the supposed superiority of ConeTrap®/ Moskisan®in protecting fruits.

This result also pointed out that until now we did not understand precisely how the mass trapping affects the Medfly population in the field and what are the factors that could influence its effectiveness. In our work a change in host plants and season: from summer fruits to citrus and from summer to fall seems to have affected the performances of trapping. Alonso-Muñoz and Garcia-Marí[16]obtained that the major factors that could improve mass trapping efficacy are to be implemented close to fruit ripening, in large areas with compact shape, and with a higher density of traps in periphery as already mentioned by (Cohen and Yuval, 2000) [17].

5. Conclusion

The new device tested ConeTrap® was as effective as Moskisan® and Magnet™MED to protect citrus fruits var. Navel until the harvest when included in an IPM program combining mass trapping or attract and kill, sanitation, spinosad sprays and monitoring.

However, it's important to note that the Medfly level in fall 2014 was unusually low comparing to previous years. Hence it will be useful to repeat the trial with a higher Medfly level. Also a replicate in a second orchard with a wise experimental design should make the results more consistent. We can also test the resistance of this system under severe climatic conditions due to its soft plastic consistency and its reuse for several years. Regarding the ease to handle of the trapping devices tested, the Conetrap® is a very practical system that could have a place in Tunisian citrus industry especially for its affordable cost to farmers as its recommended density per hectare could be reduced.Moreover, the ConeTrap® has the advantage to use a single dry attractant with a great captures capacities and resistance to very high temperatures.

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