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Article

An Integrated Decision Support System for Environmentally-Friendly Management of the Ethiopian Fruit Fly in Greenhouse Crops

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Abstract: The Ethiopian fruit fly (EFF), *Dacus ciliatus*, is a key, invasive pest of melons in the Middle East. We developed and implemented a novel decision support system (DSS) to manage this pest in a greenhouse environment in Southern Israel. *Dacus ciliatus* is commonly controlled in Israel with repeated calendar-sprayings (every 15 days) of pyrethroid pesticides. The current study compares the performance of a DSS against calendar-spraying management (CSM). DSS was based on EFF population monitoring and infestation. DSS took into consideration concerns and observations of expert managers and farmers. During 2014, EFF damage was concentrated in the spring melon production season. Fall and winter production did not show important damage. Damage during the spring of 2014 started to increase when average EFF/trap/day reached 0.3. This value was suggested as the threshold to implement pesticide spraying in DSS greenhouses. EFF/trap/day trends were derived from monitoring with conventional traps and a novel electronic remote sensing trap, developed by our group. CSM during the spring of 2015 included 3 EFF control sprays, while DSS-managed greenhouses were only sprayed once. At the end of the spring season, damage was slightly higher in DSS greenhouses (1.5%), but not significantly different to that found in CSM greenhouses (0.5%). Results support continuing DSS research and optimization to reduce/remove pesticide use against EFF in melon greenhouses. Interactions with farmers and managers is suggested as essential to increase adoption of DSS in agriculture.

Keywords: *Dacus ciliatus*; *Cucumis melo*; electronic trap; decision support system; pest control

1. Introduction

A decision support system (DSS) can be defined as a complex of tools, such as a computer programs, models, and heuristic information (i.e., experience and knowledge of farmers, inspectors, and managers), acting together to assist decision-making [1]. In insect control, DSSs have mainly been developed to manage pests of perennial trees and field crops [2–4]. DSS tools are also being widely applied in area-wide pest management (e.g., the use of GIS platforms to guide decisions on sterile Mediterranean fruit fly releases [5]). However, to the best of our knowledge, DSS has not yet been field implemented for insect pest management (especially against fruit flies) in greenhouses. The present study illustrates such an attempt providing all elements of the development of the DSS and results of a field test. The DSS that was developed and described in this study was applied against a major fruit fly pest of Galia melons (*Cucumis melo*) cultivated inside plastic tunnels ("greenhouses") in an arid region in Israel. A Tephritid fruit fly, *Dacus ciliatus* Loew (the Ethiopian fruit fly, EFF), is the key pest of this crop in this region. *Dacus ciliatus* invaded Israel most likely from Egypt in the late 1990s [6], and, since then, has been contained in the Arava area in Southern Israel [7]. Without chemical control, the damage inflicted by the EFF to commercial melons can be absolute (Rami Sadeh, Melon Grower and agricultural expert, Ein Yahav, Arava, Israel, Personal Communication).

As with most Tephritids, female EFF lay eggs in fruits [8]. Larvae develop within the fruit mesocarp, which destroys the commercial value of the product. Fully developed third instar larvae drop out from the fruit through an emerging hole and pupate inside the soil. After an incubation period, metamorphosis is completed and adult flies emerge from the puparium. Depending on the environmental temperature, adult EFF take from 10 days to 30 days to attain sexual maturation, mate, and initiate egg-laying, which gives rise to the next generation. The EFF is an oligophagous insect, developing mainly on plant species of the family Cucurbitaceae [8].

Based on Maklakov et al. [6], farmers in Israel use pyrethroid insecticides to control the EFF. The application regime follows a calendar pattern, with cover-sprays of melons every 15 days. Spraying activities are initiated once the first flies are detected (monitored only by yellow-sticky traps in the growing area [9], since there is no specific chemical attractant known for this fly [10]). Additional pesticide applications (usually implemented every second week), however, are conducted independently of fruit damage and EFF population levels.

In 2014, we initiated a study in Southern Israel aimed at evaluating the possibility of developing a DSS for this pest in melon under plastic greenhouses. The development included: (a) a study of EFF population fluctuations throughout the planting season, (b) systematic recording of fruit infestation trends by the pest, (c) testing of automatic monitoring systems, and, (d) in conjunction with growers and pest-control experts in the area, the derivation and establishment of rules to intervene in EFF control and make decisions (i.e., development of a DSS). During 2015, we applied the proposed DSS for EFF control in a greenhouse melon growing system, and make a first evaluation of the feasibility of the system.

2. Materials and Methods

2.1. Location of Study Site

Ein Yahav is an agricultural village located in the Israeli part of the Arava Valley, south of the Dead Sea in southern Israel (Figure 1) (30°39′26″ N; 35°14′29″ E). The region is a desert with less than 200 mm of precipitation per year. Agricultural production is mainly under cover in "greenhouse" conditions (either plastic tunnels or large insect-proof screen houses, with controlled environments). Agricultural production is intensive, with irrigation derived mainly from desalinated underground water. Agricultural land extends over an area of approximately 150 ha. Peppers is the main crop in Ein Yahav (about 70% of the production land), followed by melon, tomatoes, eggplants, watermelons, dates, and grapes.

Figure 1. Location of the study site (Ein Yahav) in the Arava Valley (South Israel), and an aerial view of the agricultural area dominated by plastic greenhouses (image at the bottom of the figure). (Satellite images cropped from: https://www.google.com/).

2.2. Melon Production Systems

There are three seasons per year for melon production (*Cucumis melo* L.), in Ein Yahav: spring (from December until June, in covered plastic greenhouses), autumn (from July until November, with no plastic coverage), and winter (from October until March, in covered plastic-greenhouses). During mid-summer months, there is a "sanitation" period (July–August), during which no agricultural production takes place to reduce crop disease and vector populations. During the spring and winter, melon production takes place inside plastic greenhouses of ~720 m^2 (6 m × 120 m, 2.5 m high) (Figure 2). Climbing melons arranged in four rows are the preferred agronomic practice. Control of the EFF was conducted by applying byfenthrin (Talstar®), a type I pyrethroid [11], every 15 days after the first flies are caught in a regional surveillance system. Treatment was conducted without fruit damage assessment. Pesticide application was restricted in melon growing systems during the 15 days before harvest.

Figure 2. Typical spring and winter melon production systems under plastic greenhouses (720 m^2 each) in the Arava valley of Southern Israel.

2.3. Monitoring of Adult EFF and Damage: Pre-DSS Assessment

To determine periods of EFF activity, in 2014, we undertook intensive monitoring in the melon growing areas of Ein Yahav using yellow sticky-trap boards (YSB) (Rimi®, Petach Tikva, Israel) (Figure 3, insert). All melon-growing greenhouses in this area were monitored by placing YSB in both entrances of the greenhouses in the northern and southern sites (Figure 3). In addition, we monitored sections surrounding the melon production areas. We set 78 YSB throughout the 2014 season and inspected them once or twice per month (from April 2014 to January 2015). The number of EFF caught are reported as Flies/Trap/Day (FTD).

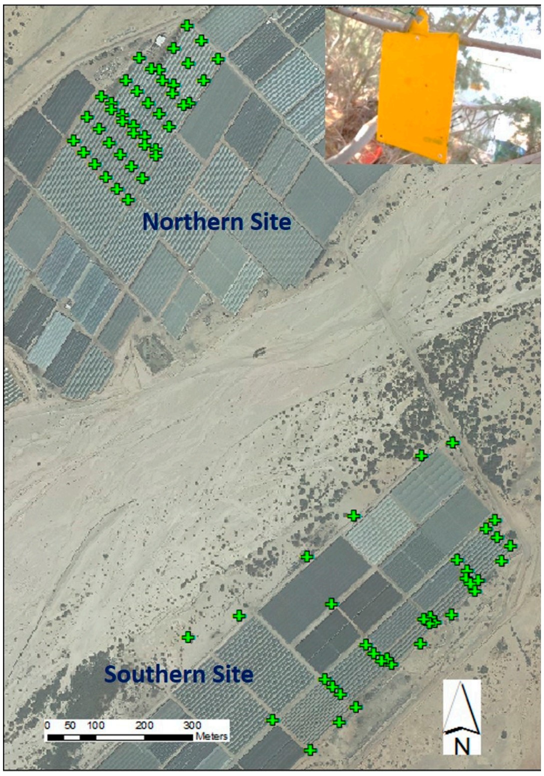

Figure 3. Aerial image of the northern and southern melon growing sites in Ein Yahav and position of yellow sticky trap boards (green crosses) used to monitor the Ethiopian fruit fly during 2014. The insert picture shows a Rimi® yellow sticky trap board (YSB). YSB were suspended in entrances of greenhouses (gray lines in the aerial photo), and in surrounding vegetation.

Damage to melon fruit was assessed by inspecting 100 melon fruits per tunnel on each inspection date. Selection of melon fruit for inspection was conducted by walking a predetermined number of steps (5 steps) within the growing line, stopping and picking the first available fruit. Damaged fruits (i.e., with signs of EFF egg-laying and larval development) were registered but not removed ("sampling with substitution"). All four rows of each tunnel were sampled by this method (25 fruits per row). Inspections for damage were conducted during the spring of 2014 (covered melon greenhouses), fall of 2014 (open system, tunnel location areas were the same, but tunnel plastic covers were removed), and winter 2014–2015 (covered system). Damage was assessed in 20 greenhouses in the southern site and 14 greenhouses in the northern site (Figure 3). During the spring of 2014, damage was assessed during three dates (i.e., after detection of the first flies in traps and after the fruit became sensitive): 17 April, 1 May, and 15 May. After these dates, all melon greenhouses were cleaned from vegetation to enter the annual "sanitation" period. Following a similar protocol to that of the spring, damage to fall melons of 2014 was assessed during 3, 17, and 31 September, 2014. Winter damage was assessed on 22 December, 2014 and 6 and 22 January, 2015.

To establish a threshold of adult captures as an input to the DSS, we correlated the average regional cumulative trapping of EFF for the period between damage-assessment dates ("pre damage-assessment period", PDP) with observed damage levels inflicted by the EFF at the time of damage assessment. Therefore, the average cumulative number of flies trapped during the PDP were correlated with the average damage in melon at the subsequent damage assessment date, which was, in fact, the end of the PDP. For this aim, we calculated the average capture per sampling date for the entire site (southern or northern), which were used to derive the cumulative average number of EFF captures per day (FTD) for each growing site (south or north). Average damage was assessed in each growing site (south or north) independently. Correlation between cumulative number of FTD and damage was only performed in spring 2014. Melon damage was insignificant during the fall and winter growing seasons (see Results section). The accumulation of average FTD for the spring season started on 10 April, 2014, where the first EFF were caught in the YSB. Damage assessment was performed on three dates: 17 April, 1 May, and 15 May, 2014. The correlation analysis was based on the FTD during the PDP and the average damage at the end of the periods. The northern and southern sites were used separately in the calculations ($n = 6$). The threshold for the DSS was derived from: (1) the results of spring 2014, (2) experts and farmer's experience and knowledge, and (3) the general long-term objectives of growers to completely remove pyrethroid utilization in the melon system to implement integrated pest management measures, such as the release of beneficial predatory mites to control red mites. This threshold level is preliminary and a tool to explore the development of DSS for this crop and pest.

2.4. Decision Flowchart: A Guide for EFF Control

To reduce pesticide utilization toward abandoning the calendar-spraying management practice of EFF in melon production in greenhouses, a decision-flowchart guideline was designed together with experts and the main melon grower in the area. The decision flowchart (Figure 4) supported decision making for cover spraying of greenhouses. This, in fact, is a compromise between risk-taking of farmers and pest expert managers, and the exploration of pesticide application reduction. Decisions were made based on intensive monitoring of EFF trapping and fruit damage. The initial compromise with the pest expert and farmer was to break the established calendar-spraying of 15 days by adding an extra week, up to 22 days ("farmer's risk limit"), without spraying, and applying a threshold average trapping number of FTD in the area, based on the results of the previous year (2014). That is, to spray every 22 days, but if FTD increased above 0.3 during that extra week we were expected to spray. The compromise also included the application of pesticide after 22 days, regardless of the FTD threshold, as a preventive measure requested by the farmer to avoid damage and buildup of undetected EFF populations. In fact, this last compromise was reassessed and modified during the implementation phase due to real field conditions and observed damage dynamics (see Results section). All traps placed during 2015 in the southern site were used to estimate threshold FTD. The DSS algorithm for the

EFF was programmed in Excel (as a first management step). The farmer and the research team based all implemented decisions on the suggestions of this algorithm, the comparative results derived from the intensive damage assessment, the proximity to harvest, and the pest-expert and farmer's knowledge as well as risk-taking inclination during implementation. This last aspect had an important weight at the time of decision-making, as evident during the system-testing period in the spring of 2015.

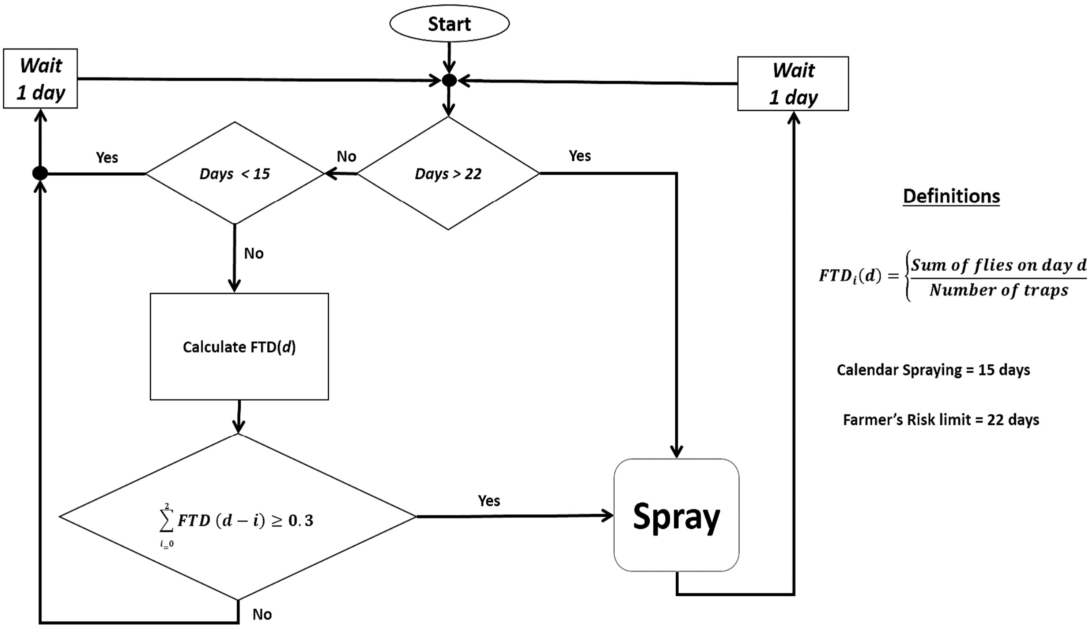

Figure 4. Flowchart of the algorithm developed for the decision-making on pesticide spraying against the Ethiopian fruit fly during melon production in greenhouses in the spring of 2015 in Ein Yahav. The decision-making algorithm is a compromise between calendar spraying, usually performed by the farmer every 15 days, and an extra 7 days without spraying in which risk was tolerated by the farmer and pest-expert, but dependent on the accumulation of flies/trap/day (FTD) in the area.

2.5. DSS Assessment Setting

During 2015, we examined the implementation of the DSS to control the EFF in the Arava valley of Israel. Based on the results of 2014, and that in 2015 the main grower in Ein Yahav reduced the area of melon production, we concentrated our efforts on the main section of melon production during that year: the southern site (Figure 3). We examined all productive melon greenhouses (14, ~1 ha of melons, Figure 5). To differentiate between the two management practices (i.e., DSS-guided pesticide spraying vs. calendar spraying), we selected four greenhouses for the implementation of the DSS (marked as DSS in Figure 5) and the remaining 10 greenhouses followed calendar-sprayings of pyrethroid against EFF (i.e., control, blue strips bordered by traps in Figure 5). For comparison purposes, fruit infestation was monitored in all greenhouses. The assessment of DSS was concentrated in the spring season of 2015, which was the main season showing a clear association between EFF trapping and damage during 2014 (damage during the fall and winter seasons of 2014 was negligible).

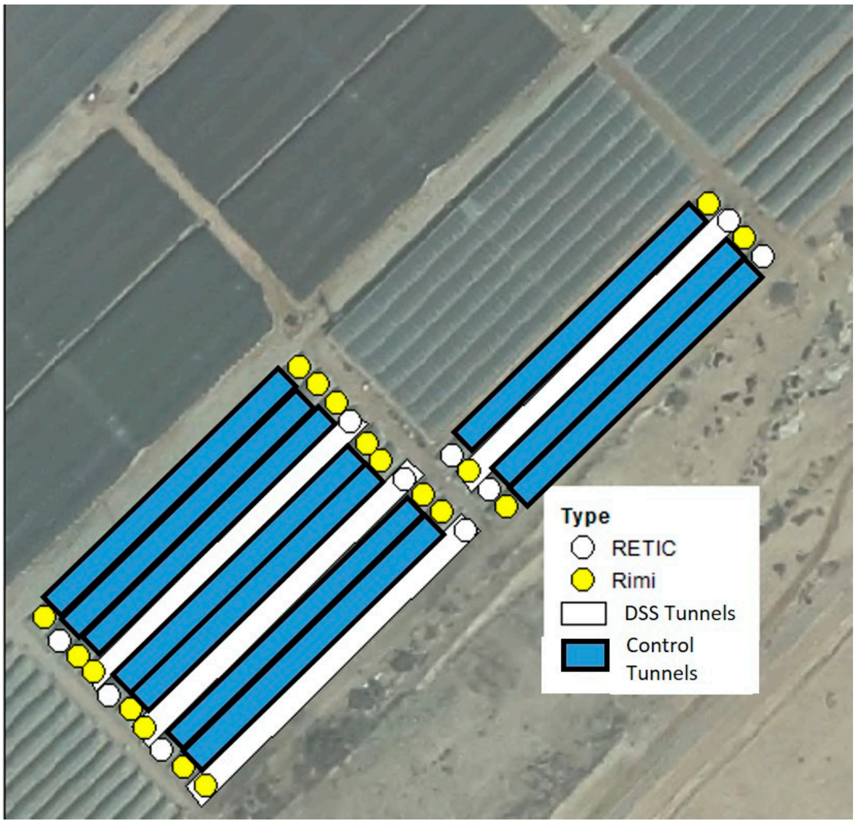

Figure 5. Aerial image of the southern melon growing area site in Ein Yahav used during the decision support system (DSS) management of the Ethiopian fruit fly in 2015. Strips show the position of parallel plastic greenhouses. White strips (4) were those greenhouses used for DSS-management. Blue strips (10) with melon production were used as control greenhouses (i.e., management by calendar-spraying of the pesticide). Yellow and white dots show the position of Rimi® yellow sticky boards (yellow dots), and real-time wireless trapping system (white dots, RETIC) used to monitor the Ethiopian fruit fly. Monitoring systems were placed in the entrances of greenhouses where melons were grown. Only those strips flanked by either yellow or white dots produced melons during the spring of 2015 in the southern site of Ein Yahav.

EFF adult monitoring was conducted with YSBs located in both entrances of growing greenhouses (as in 2014) (Figure 5). Manual monitoring is labor intensive and might not be practical. Therefore, to test an automatic monitoring system, we replaced some of the simple YSBs with a real-time wireless automatic trapping system developed for the study to monitor EFF populations remotely in the DSS study area (Figure 5, labelled as RETIC-Real Time Insect Counting Trap, and Figure 6). The electronic design, reliability, and performance of the RETIC automatic trap has been recently reported by Shaked et al. [9]. Pictures of the YSB in each RETIC-trap were obtained at least once a day, and the image sent via 3G connection to the Internet, where the "digital scout" (or professional entomologist) visually examined the high-resolution images (5 Mpxl) for EFF. The camera and communication were processed by a solar powered microprocessor (Figure 6). The EFF monitoring set for this assessment and application of DSS principles initiated on 2 March (shortly before spring melon fruits became susceptible) and continued until 1 June, 2015 (after the spring melon harvest). EFF monitoring was conducted with 28 traps (7 RETIC and 21 simple YSBs, Figure 5), with scouting visits to traps twice a week (to follow populations closely and to corroborate the RETIC performance). The average number of FTD were estimated for the whole area (i.e., the FTD derived from each tunnel were not used). Derived average FTD was used for the DSS. YSBs (also those of the RETIC system) were substituted once a month.

Figure 6. Image of a RETIC-Real Time Insect Counting Trap, wireless, monitoring system in the gate of a melon growing greenhouse in Ein Yahav, Arava Valley, during the spring of 2015.

Damage in all greenhouses was assessed following a similar methodology as in 2014. During the DSS implementation period, we conducted 14 melon-damage weekly counting sessions. Fruit infestation counting started on 11 March and finished on 25 May 2015. Average infestation rates for each management scheme throughout the spring growing season were contrasted using repeated measures ANOVA.

Spraying of control greenhouses (i.e., calendar-guided) with byfenthrin was conducted on three dates: 4 April, 29 April, and 15 May 2015. DSS-managed greenhouses were sprayed following the guidelines set in the decision flowchart (see Results section), rates of infested melons in both systems, and the pest-manager and farmer's heuristic experience, knowledge, and willingness to increase or reduce risk taking. No pesticides were applied after 15 May, two weeks before harvest, as required by the regulatory authorities. Sulphur and bulpirimate were also sprayed to control fungal diseases, and bifensate as an acaricide.

3. Results

3.1. EFF Patterns and Damage during the Pre-DSS Assessment (2014)

Figure 7 shows an example of EFF captures in YSBs and fruit infestation patterns in selected greenhouses in the northern and southern melon producing sites of Ein Yahav from 8–15 May 2014, a few days before the spring melon harvest. Both fruit infestation and EFF catches were much higher in the northern growing-areas of Ein Yahav compared to the less affected southern ones. Fruit infestation was >25% in three of the 14 greenhouses in the northern site of Ein Yahav, and adult trapping >0.7 FTD in eight out of 42 traps, compared to 0 out of 20 greenhouses with >25% in the south and 4 out of 36 traps showing >0.7 FTD (Figure 7). Figure 8 summarizes the data for 2014: damage was higher at the northern growing site than in the southern. In addition, Figure 8 also shows the population levels of captured EFF and the fact that, during the fall and winter growing seasons (from September 2014 to January 2015), fruit infestation was negligible in both sites. It is also of interest that captures during the spring were relatively low compared to those found during the fall and winter of 2014, and they were several times greater in the north than in the south (Figure 8). Because fruit infestation was high only in the spring growing season, we correlated the trapping levels in both growing sites with EFF capture levels in each of them. The correlation between trapping levels and fruit infestation was relatively good but not significant ($r = 0.68$, $0.05 < p < 0.1$, $n = 6$). Another important observation during 2014 was that fruit infestation in the spring was only noticed when accumulated average FTD was between 0.1 and 0.3. This information, together with pest-expert managers, farmer's knowledge, and past experience, was used to develop the threshold level for the DSS applied in 2015.

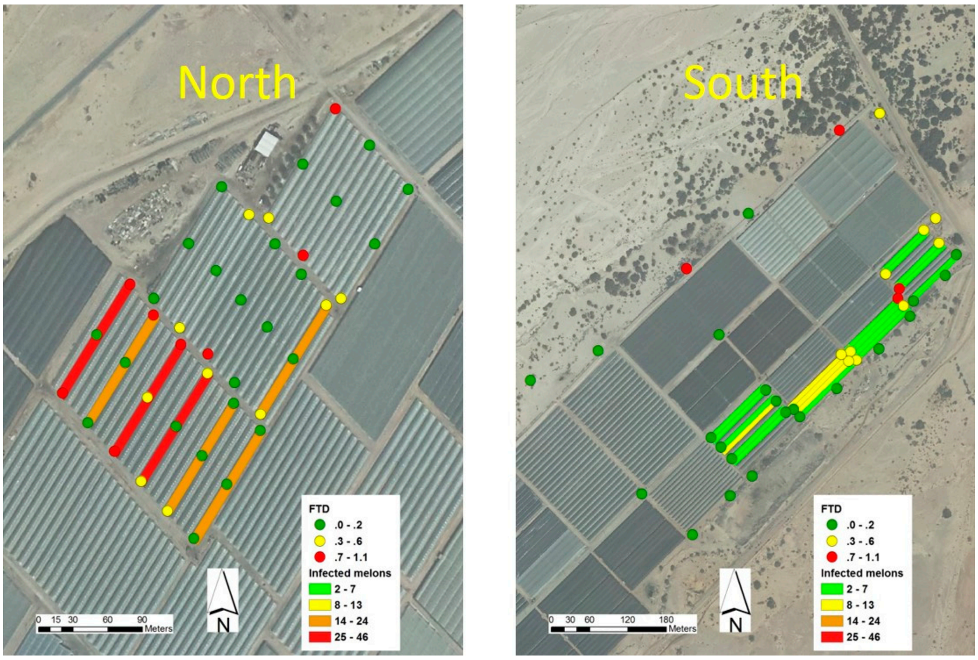

Figure 7. Map of Ethiopian fruit fly trapping-level in Rimi® yellow sticky boards (dots) and percent of infested fruit produced in plastic greenhouses in the northern and southern melon growing areas of Ein Yahav during the week of 8–15 May 2014.

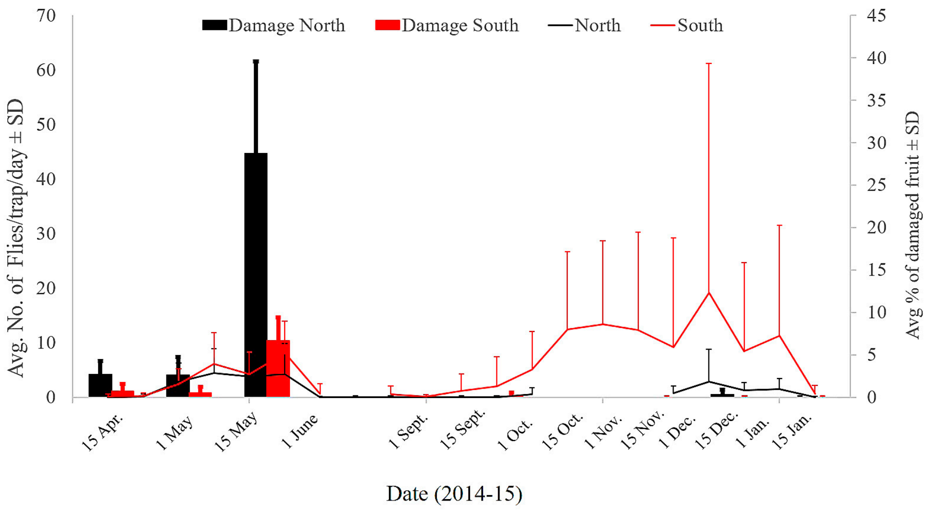

Figure 8. Average Ethiopian fruit fly trapping level in yellow sticky boards in the northern and southern melon growing areas of Ein Yahav, throughout 2014 and early 2015, and percent of fruit infestation.

3.2. Management of EFF Using the DSS (2015)

Figure 9 shows the temporal and spatial trends of fruit infestation and EFF captures in the melon growing greenhouses of the southern site during the "sensitive" spring melon season (early

March–end of May) in DSS and control greenhouses. The figure also provides the dates of pesticide (byfenthrin) application as a calendar treatment to control EFF (DSS greenhouses were managed with DSS guidelines, based on the grower's willingness to take risk). A significant increase in EFF trapping, which also coincided with first infested fruit, was detected in early April. As a result, calendar spraying started on 4 April. Since, in one of four DSS greenhouses a relatively high level of fruit infestation was recorded in early April (between 3%–5%, see situation for 12 April in Figure 9), the farmer and pest-experts decided to also spray all four DSS-managed greenhouses on this date. During the two other calendar dates of pesticide applications, together with the farmer and pest-experts, and partly based on the DSS guidelines and on the general damage levels and dynamics, a decision was made not to spray the DSS-managed greenhouses. This means that damage in both control and DSS-managed greenhouses was relatively low and very similar, which leads us, the farmer and pest-experts, to make the decision not to spray in spite of the recommendation to spray given the FTD threshold level suggested for the DSS. By 24 May, shortly before harvesting, fruit infestation levels were 1% to 3% in three out of four DSS-managed greenhouses. Fruit infestation was zero in the fourth greenhouse. Fruit infestation levels in control greenhouses, following calendar spraying, was 1% to 2%.

Figure 10 summarizes the EFF capture trends and fruit infestation patterns in both the DSS-managed and control (calendar treated) greenhouses. Average FTD values were below 0.3 throughout the early stages of melon development (up to 24 April), when adult captures started to increase. The average FTD progressively increased up to an average of 1.7 by the time of harvesting (25 May) (Figure 10). Average fruit infestation significantly increased during the spring season regardless of the management practice of greenhouses ($F_{11,167} = 3.55$, $p < 0.05$). Fruit infestation rates were similar between DSS-managed and control (calendar-sprayed) greenhouses ($F_{1,167} = 1.36$, $p = 0.2$). No significant interaction was found between the date and treatment ($F_{11,167} = 1.03$, $p = 0.4$). Average fruit infestation in the DSS greenhouses before harvest was around 1.4%, while average damage in control greenhouses before harvest was around 0.5%.

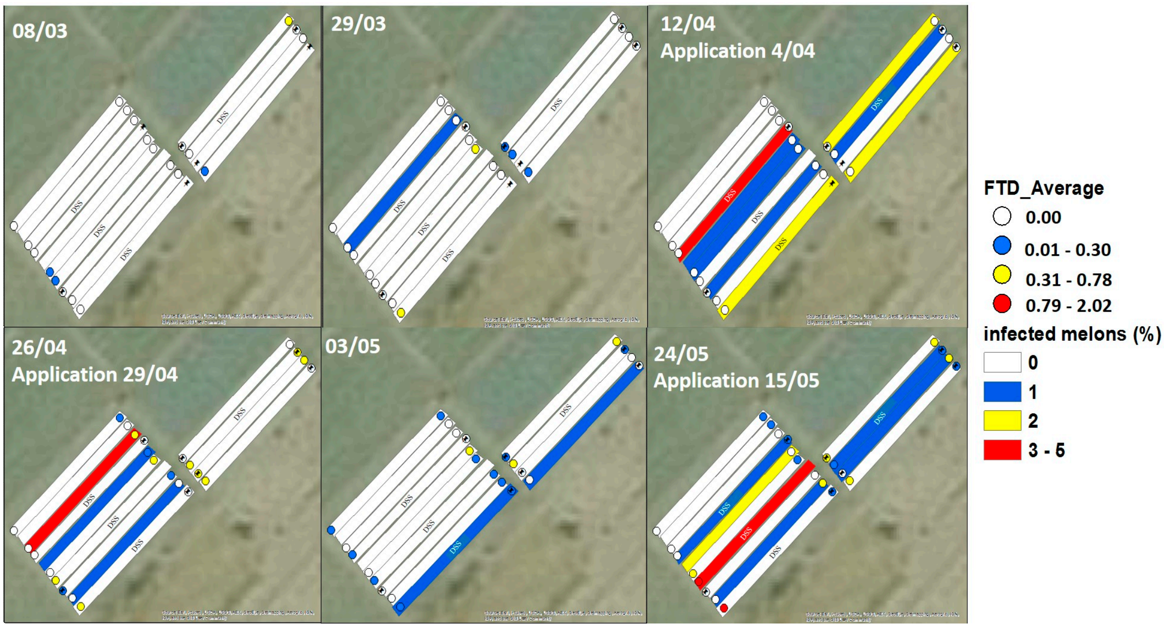

Figure 9. GIS-images of the average Ethiopian fruit fly trapping level by yellow sticky boards and RETIC traps (see Figure 5) in the southern melon growing areas of Ein Yahav, throughout spring of 2015 (several dates), and the percent of fruit infestation in the control (calendar-spraying management) and DSS-managed melon greenhouse plastic tunnels. Dates of calendar-spraying are noted within the figures.

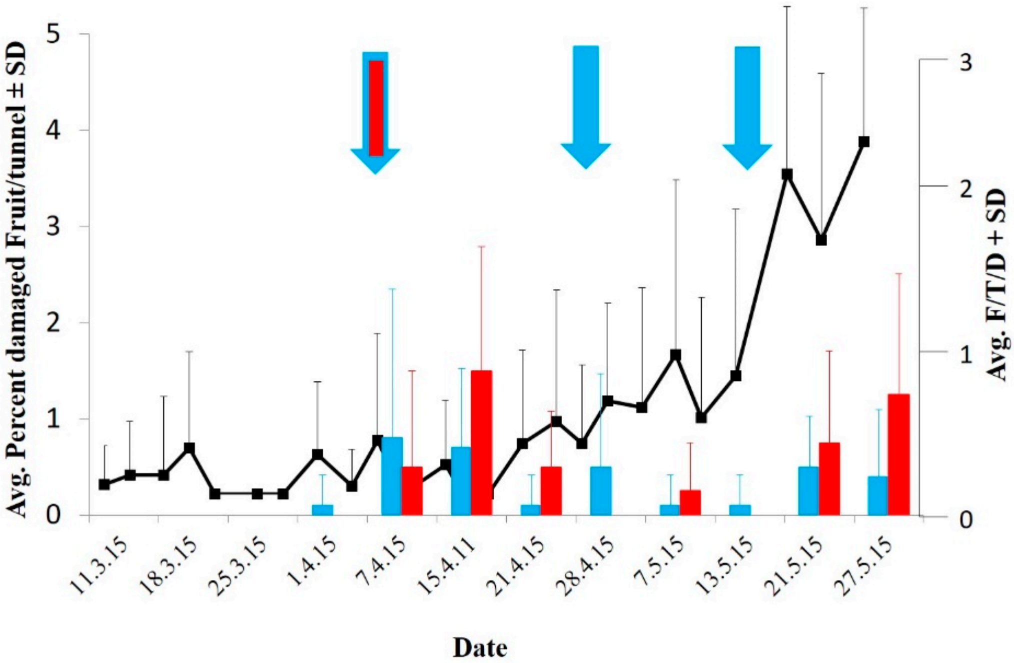

Figure 10. Average flies/trap/date (black line) during the spring of 2015 in the southern melon growing site of Ein Yahav, and percent infested fruit in DSS-managed (red bars) and calendar-spraying managed (blue bars) melon producing greenhouses. The dates of pesticide spraying are shown for both calendar-spraying management (blue arrow) and DSS-managed greenhouses (red strip inside blue arrows).

4. Discussion

During 2015, DSS-managed greenhouses received less pesticide (ca. 67%) than control greenhouses that followed calendar-spraying. While DSS management tried to rely mainly on monitoring data (both of EFF and damage), decision-making was also affected by comparative real-time melon-infestation data, pesticide utilization restrictions toward harvesting time, and the pest-expert managers and farmer's perception of the situation and willingness to take risk. During the first calendar day of application (4 April), one of the DSS greenhouses was showing a high level of fruit infestation, contrasted to all other melon-producing greenhouses. Thus, although FTD was below the threshold (<0.3 FTD), and since pest-experts and farmer were expecting an increase in damage if DSS-managed greenhouses were not treated with pesticides, it was decided to include all DSS-managed greenhouses into the calendar day spraying agenda to reduce risks of early damage in these greenhouses. No signs of fruit infestation were detected in the DSS-managed greenhouses on the second calendar spraying date (29 April) (Figure 9) and EFF adult captures were just starting to increase (Figure 10). Thus, together with the farmer and pest-expert manager, the recommendation of the algorithm was followed, and the farmer abstained from spraying DSS-greenhouses for another seven days. The expected spraying of DSS-managed greenhouses on 6 May, however, was also omitted due to the low general level of EFF infestation in control and DSS-managed greenhouses. This was also due to our interest and the pest-expert manager's curiosity to explore an extension of the period with no pesticide spraying of the DSS-managed greenhouses. The following calendar application occurred on 15 May, when EFF trapping levels were already above threshold numbers, and fruit infestation was increasing (Figure 10). In spite of the DSS recommendation to spray DSS-managed greenhouses during this date, however, it was decided together with the farmer and pest-expert manager to abstain again from spraying DSS-managed greenhouses, by retaining this situation until harvest. After 15 May, spraying was forbidden by regulation. This combined management led to a slightly higher (but not significant) average damage level in DSS-managed greenhouses in contrast to control greenhouses (ca. 1.5% in DSS and 0.5% in control greenhouses at the time of harvest).

The benefits of reducing pesticide utilization against EFF are not merely economic, which, at this stage, is marginal. In fact, the general objective is to transform melon greenhouses in the Arava to IPM managed systems. The average melon yield for a 0.1 ha plastic tunnel is around 8 tons. Cost of melon production per 0.1 ha at the time of the study approximated € 4,800, while income amounted to approximately € 7000/ha. Cost of spraying pyrethroid against the EFF per 0.1 ha was around € 6 per treatment. Thus, reducing pesticide treatments against EFF from 3 to 1 applications was a marginal economic saving of € 12/0.1 ha, which corresponds to 0.25% of production costs. This marginal cost, thus, is not expected to be an effective incentive for growers to completely modify their EFF control strategies of calendar spraying. The main motivations, however, comes from the higher costs associated from controlling red mites with pesticides (€ 120/0.1 ha) and the benefits associated with the introduction of biological control agents to control mites and other pests, which are affected by the utilization of pyrethroid. In addition, reducing pesticide utilization in melon growing, besides the beneficial effect upon the environment, also reduces the risk of farmers to incur administrative fines of € 1200/ton if pyrethroid pesticide residues are detected in their fruit by the routine Ministry of Health inspections. This risk and associated costs are, in fact, a central incentive in reducing pesticide use, and introducing Integrated Pest Management (IPM) and biological control strategies into melon production in the Arava.

The present DSS was specifically developed for the EFF in the Arava, and followed the farmer and expert's needs, risk-aversion, and heuristic knowledge. Thus, we do not expect that the suggested system can be generally applied elsewhere in the world, where the EFF create damage. However, the methodological approach can be used as a guideline for the development of locally adapted DSS for the EFF and other insect pests, responding to the local needs and farmer's expectations. In addition, and due to the fact that the DSS is the result of a single year of testing, the suggested DSS still requires further research, optimization, and development before it can be generally used in the Arava for the management of the EFF and the incorporation of biological control in melon greenhouses.

The incorporation into agriculture of DSS in pest control has been slow, and we are not familiar with any broad application yet of IPM DSS for insect control in agricultural production. Cohen et al. [1] pioneered the development and application of IPM-DSS. Their development of a spatial DSS (MedCila) to manage the Mediterranean fruit fly (medfly), *Ceratitis capitata* (Diptera: Tephritidae), in citrus orchards in Israel was one of the first attempts to integrate such systems into insect pest control, and one of the first to add the spatial component into the decision support system as part of an area-wide IPM approach. MedCila not only helped reduce pesticide utilization to control medfly in citrus orchards (by at least 8%), but also provided evidence of the acceptance of pest-protection inspectors and farmers to adopt DSS to increase their risk and reduce pesticide utilization at an area-wide range [3]. Decisions made by pest control managers was an interactive activity in which the spatial DSS provided more information to managers that were able to make a "learned" decision on pesticide application [3]. In our case, we followed a similar approach: the farmer and pest-expert manager obtained information from active "real-time" scouting, and took decisions based on their heuristic (i.e., past experience and knowledge) approach and intuition. This led to a 67% reduction in pesticide use. The introduction of automatic monitoring traps, like the ones used and tested in this study, may also lead to additional reduction in spraying actions, which was recently shown by Goldstein et al. [12]. The slow adoption of DSS into pest control is likely related to the intrinsic behavior of farmers and managers to reduce risk. An interactive, and heuristic approach to DSS application, as shown by Cohen et al. [3] and, in this study, may be a "careful" strategy to increase the incorporation DSS into pest control in agriculture.

Greenhouse production, or "protected cultivation," is on its rise throughout the world and is becoming an important system of food production [13]. Many novel aspects are being developed, which include better engineering and environmental control, crops, and cultivation techniques, water and nutrient management, and IPM [13]. Insect pest management in these controlled environments can greatly benefit from the application of DSS in environmental management and control of structure ventilation to reduce pest invasions. DSS can be specifically developed for application of beneficial insects in time and space and other measures that reduce pest population inside protected environments. In fact, some private companies specializing in greenhouse production and pest control, especially with beneficial insects, are already incorporating unpublished protocols to time the release of predators based on pest levels and monitoring (David Ben-Yakir, ARO, personal communications). As suggested by the results of this study, and past experiences [1,3], we expect that intelligent-DSS derived from research and grower's, and manager's, heuristic knowledge and feedback will become a major strategic tool in the development of IPM in protected cultivation systems in the future.

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