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Full Length Research Paper

Effect of different pesticide application methods on spray deposits, residues and biological efficacy on strawberries

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In agricultural food production, positive results can be obtained by using appropriate pesticides through the application of appropriate methods. In this study, we aimed to determine the effects of different spraying methods on spray deposits and drift, pesticide residues and biological efficacy on strawberries. For this purpose, strawberries were sprayed with dicofol by broadcast and band spraying. The effectiveness of different application methods was studied on 09 May, 2007 and 16 April, 2008. Broadcast sprayings were applied via hollow cone nozzles (HC) and air-assisted spinning cage nozzles (ASC). Band spraying was applied via flat fan nozzles (FF). Pesticide deposits on leaf surfaces, ground, drift and pesticide residues on strawberries were analyzed with Gas Chromatography/Electron capture detector (GC/ECD). Strawberries were analyzed based on dicofol residues up to 6 days after spraying. The results obtained showed that the highest pesticide deposits on leaf surfaces and also biological efficiency were obtained with FF in 2007 and 2008. The lowest pesticide deposits on ground were obtained by HC and the highest deposit of drift was obtained by ASC in 2007 and 2008. According to Commission Directive 2000/42/EC, the MRL's of dicofol on strawberry is 0.02 mg/kg. In this study, residues on strawberries for all types of nozzles were below the suggested maximum residue level (MRL) of dicofol by Commission Directive 2000/42/EC in 2007 and 2008.

Key words: Broadcast spraying, band spraying, hollow cone nozzle, flat fan nozzle, air-assisted spinning cage nozzle, biological efficacy, red spider mites, gas chromatography, electron capture detector (ECD).

INTRODUCTION

In modern quality agricultural food production, efficient results can be obtained by the use of suitable pesticides and their application methods. Broadcast spraying, which is used by farmers due to easy application, covers the pesticides in all field area. On the other hand, band spraying is defined as covering the pesticides in all band width where pesticides are applied on crops for insecticides and fungicides, and on soil between crops row spacing for herbicides. Some farmers use band spraying method for strawberry pest management. Band spraying is regarded to be more economical compared to broadcast spraying, since the row application kit ensures that the pesticide goes where it is directed, resulting in a more effective application (Landers, 2007). Moreover, band spraying has advantages such as reduction in pesticides and water use per hectare (Debear et al., 2005).

Different nozzles such as hollow cone, flat fan, and spinning disc/cage (with/without air-assistance) are some of the main types used in broadcast spraying method. Hollow cone (HC) and flat fan (FF) nozzles can be used

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in high, normal and low volume applications. Spinning disc/cage nozzles with/without air assistance can be used in low and ultra-low volume applications. In spraying, using spinning disc/cage nozzles with air assistance improves leaf coverage through the plant canopy, provides better coverage to the underside of leaves, enables more penetration into crop canopy, and covers more acres per load (Taylor and Andersen, 1989; Panneton et al., 1996; Holownicki et al., 2000; Panneton et al., 2000a, Panneton et al., 2000b; Bayat and Yarpuz-Bozdogan, 2005). In Turkey, hollow cone nozzles are widely used in broadcast spraying.

Pesticide residue on strawberries is very important and has negative affects on human health (Goodwin et al., 1984; Kilmer et al., 2001; Safi et al., 2002). Some researchers use gas chromatography-electron capture detector (GC-ECD) for pesticide residues on vegetables and fruits (Stensvand and Christiansen, 2000; Safi et al., 2002; Yenisoy-Karakas, 2006; Guardia-Rubio et al., 2007).

There are many harmful insects and mite species causing injuries to strawberry roots, leaves and flowers. Red spider mites (RSM) (Acarina: Tetranychidae) are often considered as major pest acari of strawberry, destroying the mesophly cells of leaves and high population densities that can result in the plant being dwarfed or killed (Yigit and Erkılıç, 1992). Damage is expressed as stippling and bronzing of the leaves and leave's veins. Plants that sustain greater numbers of RSM may become severely weakened and appear stundent, dry, and red in coloration. *Tetranychus urticae* Koch and *Tetranchus cinnabarinus* (Boisd.) were more common RSM species in Turkey and they were recognized as pest (Oncag and Cengiz, 1978). There are a few studies regarding use of various spraying techniques for controlling of RSM on strawberry. Labanowska et al. (1996) compared two spraying techniques for the control of *T. urticae* and grey mold *Botrytis cinerea* on strawberry by testing three different spray liquid volumes 260, 400 and 550 per hectare and two doses of pesticides. They found that all spray volumes sufficiently controlled the *T. urticae*, but full recommended doses of the pesticides must be used.

In this study, different pesticide application methods were used against strawberry pests. The aim of this study was to determine the effects of different pesticide application methods on spray deposits, spray drift, pesticide residues and biological efficacy on strawberries. Air assisted spinning cage nozzles (ASC) were utilized as an alternative to the hollow cone (HC) nozzles in the broadcast method and the flat fan (FF) nozzles were used in the band spraying method.

MATERIALS AND METHODS

Location

In this study, strawberries (Fragerria X ananassa, Duch, Rosaceae) were grown in research experimental fields of the Yaltir Corporation in Adana which is in the Mediterranean region of Turkey. The spraying experiment was designed as a complete randomized block with four replicates; also 10 plants of cultivar camarosa species were randomly selected in each replicate. Each plot covers 10 m in length and 5 m in width. The effectiveness of different application methods was studied on 09 May, 2007 and 16 April, 2008.

Pesticide

In this study, 0.292 kg a.i. ha^{-1} dicofol/Kelthane™ was used for strawberries. Maximum residue level (MRL) value of dicofol is 0.02 mg/kg (EC, 2000).

Spraying methods

Two different types of spraying methods were used: (1) broadcast spraying method with hollow cone nozzles (HC) (200 l/ha) and air-assisted spinning cage nozzles (ASC) (20 l/ha), and (2) band spraying method with flat fan nozzles (FF) (200 l/ha) (Table 1). Only one field sprayer was used. The following options were applied onto the field sprayer:

1) Hollow cone (HC) nozzles (Taral™, D4-45, 50 cm above the crop) as broadcast spraying.
2) Air-assisted spinning cage (ASC) nozzle (Micron™, fan/atomizer speed 4000 rpm) as broadcast spraying. ASC nozzles were situated towards ground plane with an angle of 45°.
3) Row application kit with flat fan (FF) nozzles (Arag™, 11001, one directed towards the centre and two towards the sides of the crop) as band spraying.

The forward speed of the tractor was 6.5 km/h and the power-take-off (PTO) rotational speed was 540 rpm. The spray boom of the field sprayer (HC) covered 4 rows of the strawberry plantation in one swath. On the other hand, the spray boom (single-sided) of the field sprayer with FF and ASC nozzles covered two rows of the strawberry plantation in one swath. Each trial was repeated four times.

Meteorological conditions

During the trials, temperature, wind velocity and relative humidity were recorded. They were measured by digital Hotwire Anemometer CE (Lutron™ AM-4204 HA) and digital Humidity/type k Thermometer CE (Lutron™ HT-3006 HA). Details of meteorological conditions during experiments were shown in Table 2.

Artificial sampling methods of spray deposit on plant and the ground and drift measurements

Spray deposits were evaluated by fixing filter papers (Schleicher and Schuell, Germany), 30 × 30 mm dimension, on the upper and lower leaf surfaces at four leaves (left, right, front and back) on strawberry plants. For each replication, 10 plants were used. Spray deposits on the ground were collected on three wooden wedges to which filter papers (30 × 40 mm) were attached and placed between rows. The drift measurement was laid perpendicular to the line of travel of the sprayer and parallel to the wind direction. Using the method described by Rowinski et al. (1994), spray drift were placed horizontally along the line of measurement at distances of 1, 2, 3, 4, 5, 7.5, 10, 15, 30 and 50 m respectively, from the end of the boom. The average deposits on plant and the ground, and drift deposits were evaluated separately. After spraying, the filter paper samples were collected from field and placed in bottles (height: 9

Table 1. Details of pesticide application methods.

Pesticide application methods	Pressure (bar)	Flow rate (L min^{-1})	Application rate (L ha^{-1})	VMD (µm)	Air-Assisted velocity (ms^{-1})
Broadcast spraying					
HC	9.5	1.07	200	250	-
ASC	1.2	0.13	20	100-120	25
Band spraying					
FF	1.2	0.22	200	200	-

Table 2. Details of meteorological conditions during experiments.

Year	Pesticide application methods	Spraying time (h)	Temperature (°C)	Relative humidity (%)	Wind speed (m/s)
2007	Broadcast spraying				
	HC	09:55 – 10:03	24.3 - 25.5	59.1 – 61.9	2.7 – 3.6
	ASC	15:14 – 15:26	30.1 – 31.1	45.8 – 47.2	0.8 – 1.4
	Band spraying				
	FF	11:24 – 11:43	29.3 – 32.8	42.6 – 50.0	1.5 – 2.7
2008	Broadcast spraying				
	HC	10:40 – 10:48	24.0 – 25.6	58.1 – 63.0	0.3 – 1.3
	ASC	08:39 – 08:57	21.1 – 22.6	64.4 – 68.6	0.2 – 1.5
	Band spraying				
	FF	09:56 – 10:14	21.1 – 22.8	65.1 – 70.1	0.4 – 1.1

cm; diameter; 4.5 cm) and taken to laboratory.

Spray deposits on leaf surfaces of strawberry plants

For spray deposit on leaf surfaces of strawberry plants, four leaves (left, right, front and back) were randomly picked for each replication. For each replication, 10 plants were used. After spraying, leaves were collected from field and placed in bottles (height: 9 cm; diameter: 4.5 cm) and taken to laboratory.

Pesticide residues on strawberries

Strawberries were collected after the first hour (accepting as zero) then first, second, third, fourth, fifth and sixth days after spraying for the residue analysis. They were randomly sampled 1 kg in each plot. The samples were kept in plastic bags.

Extraction

Liquid-liquid extraction method was used. Strawberry samples and leaves were weighed and transferred to a steel blender (Waring Commercial Blender™). 100 ml acetone was added then blended. The sample was filtered with suction. The collected extract was poured in 250-ml suction flask. Later 40 ml sample extract was placed in 1 L separator funnel for liquid/liquid partitioning; 50 ml petroleum ether and 50 ml methylene chloride were added into the separator. The lower layer was transferred to a glass flask, while the upper layer was filtered through anhydrous sodium sulfate to eliminate residual water. The gained mixture was poured into evaporation tube (200 ml) of TurboVap System (Caliper Life Sciences™). The solution in the evaporation tubes was evaporated under nitrogen by TurboVap System. The resulting solution was ready for injection into the gas chromatograph.

Analytical equipment

An Agilent (6890 – 7683B auto-sampler) gas chromatograph equipped with an electro-capture-detector (ECD) and a HP-5MS capillary column (Agilent Technologies), stationary phase of 5% Phenyl Methyl Siloxane (30 m × 0.25 mm i.d., 0.25 m film thickness) and nitrogen as the carrier gas (60 ml/min) were used. A split/splitless injector was used in the pulse splitless mode. The chromatographic conditions were: detector temperature was 290°C, capillary column temperature 325°C. The analytical procedure was applied according to GC methods (Pesticide Analytical Manual, 1999). The maximum residue levels (MRL) were adopted from Commision Directive 2000/42/EC.

Sampling of red spider mites

Ten plants were randomly selected in plots representing each spraying technique and one middle leaflet near to bottom section was picked from each selected strawberry plant. These leaflets were wrapped in packing paper (250 g), placed in insulated cool containers and transferred to laboratory. Specimens of red spider mites on the leaflet samples were counted under a stereomicroscope with ×45 magnification on the same day (Nelson and Show, 1975). Larvae, nymphs and adult stages were pooled into one category as mobile mites (MM). Samples were taken in the periods March 27 - May 22 (9 weeks) in 2007 and March 17 - May 12 in 2008 (9 weeks).

Statistical analysis

All data were analyzed with randomized block design methods using an SPSS package computer programme (SPSS, 1993). Significant differences between mean values were based on Duncan's multiple range tests (Duncan, 1955). Residues on strawberry and deposits on plant, ground and drift were used to compare the results of the different application methods. Comparisons of the mean numbers of red spider mite were quantified by the one-way analysis of variance (ANOVA) at $P < 0.05$. Their mean values were grouped by the Tukey's reliability test at $P < 0.05$. Henderson-Tilton formula (Henderson and Tilton, 1955) was used to calculate the corrected mortality (percentage).

RESULTS AND DISCUSSION

Artificial sampling methods of spray deposit on plant and the ground and drift measurements

The highest total average deposits were obtained from FF nozzles in 2007. Contrary to this, the results in 2008 showed that the highest total average deposits obtained from HC nozzles (Table 3). For trials conducted in 2007, the wind speed in HC nozzles was higher than other nozzles. For this reason, the total average deposits from HC nozzles in 2007 were lower than HC nozzles in 2008. Although pesticide deposits on upper and lower leaf surfaces of plants in ASC nozzles were lower than HC nozzles, no statistical difference was observed in 2007. However, in 2008, pesticide deposits on upper leaf surfaces in FF nozzles were lower than ASC and HC nozzles. In statistical analysis, pesticide deposits in FF, HC and, ASC nozzles were different from each other. Average pesticide deposits on upper leaf surfaces were found to be higher than average pesticide deposits on lower leaf surfaces of strawberries in HC both in 2007 and 2008.

Gan-Mor et al. (1996) reported that the air-streams enhanced spray deposition on the underside of leaves. In this study, air assist (ASC) improved the average deposit of lower leaf surfaces in 2008. Sumner and Herzog (2000) evaluated that the air-assisted sprayers offered better coverage than the other sprayers on the undersides of leaves and good coverage on the topsides. Manor et al. (1989) reported that the lower leaves droplet coverage and defoliation results were better with air-sleeve sprayer than with hydraulic sprayer. Similar results were found in this study. However, average pesticide deposits on lower leaf surfaces were similar to average pesticide deposits of upper leaf surfaces in ASC in 2008. Also, average pesticide deposits on lower leaf surfaces were lower than upper leaf surfaces in ASC in 2007.

The highest pesticide deposits on ground were obtained with FF in 2007 and 2008 (Table 4). The highest spray drift was obtained at the first point (1 m) and the lowest spray drift was obtained at the last point (5 m) in all pesticide application methods in 2007 and 2008 (Figure 1). Thus, spray drift reduced when the distance was increased.

The highest spray drift was obtained with ASC in all pesticide application methods both in 2007 and 2008. ASC obtanied smaller droplets than HC and FF. Small droplets can drift long distances because of their light weight (Wolf, 1997; Ozkan and Derksen, 1998; Matthews, 2000; PISC, 2002).

Spray deposits on leaf surfaces of strawberry plants

The highest pesticide deposits were obtained with FF nozzles in 2007 and 2008 (Table 5). Yet, in 2007 no statistical difference was observed in FF and HC. In statistical analysis, pesticide deposits in FF and HC were similar in 2008 (Table 5).

Pesticide residues on strawberries

Pesticide residues on strawberries of dicofol applied at different pesticide spraying methods are shown in Table 6. Residues were detected on the strawberry samples in all spraying methods. The highest residues in 2007 and 2008 were recorded for HC ranging from 0.0347 - 0.0164 mg/kg and 0.1479 - 0.0189 mg/kg, respectively. The lowest residues were recorded for ASC, ranging from 0.0218 - 0.0086 mg/kg in 2007 and finally for FF, ranging from 0.0797 - 0.0069 mg/kg in 2008. The 10 fold increase in spray volume between the LV (20 l ha^{-1}) and MV (200 l ha^{-1}) applications gave a greater increase in residue compared to the 2.5 fold reduction in volume median diameter (VMD). Cross et al. (2000) obtained similar results in efficacy of strawberry spraying.

Average pesticide residues on strawberries of dicofol applied through different pesticide application methods are shown in Table 7. When the application methods are compared, the highest pesticide residues were obtained in HC in 2007 and 2008. In statistical analysis, pesticide residue in HC was different from others. Although pesticide residue in ASC was lower than FF, no statistical significant difference was observed in 2007. However, in 2008, pesticide residue in FF was lower than ASC and in statistical analysis; pesticide residue in FF was different from ASC. Nordmark (1994) reported that a band sprayer resulted in better uniformity and less contamination of the environment than air-assisted boom sprayer. These pesticide application methods were more efficient than broadcast boom sprayer with hollow cone nozzles in vegetables and strawberries.

Table 3. Average pesticide deposit (µg/cm^2) on upper and lower leaf surfaces of plants.

Pesticide application method	Average pesticide deposit (µg/cm^2)*					
	2007			2008		
	Upper	Lower	Total	Upper	Lower	Total
Broadcast spraying						
HC	0.466 a	0.029 a	0.495	6.289 c	0.177 a	6.466
ASC	0.301 a	0.020 a	0.321	2.203 b	2.601 c	4.804
Band spraying						
FF	16.065 b	2.090 b	18.155	1.370 a	1.685 b	3.055

* Different letters in the same column indicate significant differences (P < 0.05) by Duncan test.

Table 4. Average pesticide deposit on ground.

Pesticide application methods	Average pesticide deposit (µg/cm^2)	
	2007	2008
Broadcast spraying		
HC	0.906	0.654
ASC	0.989	0.789
Band spraying		
FF	2.423	1.101

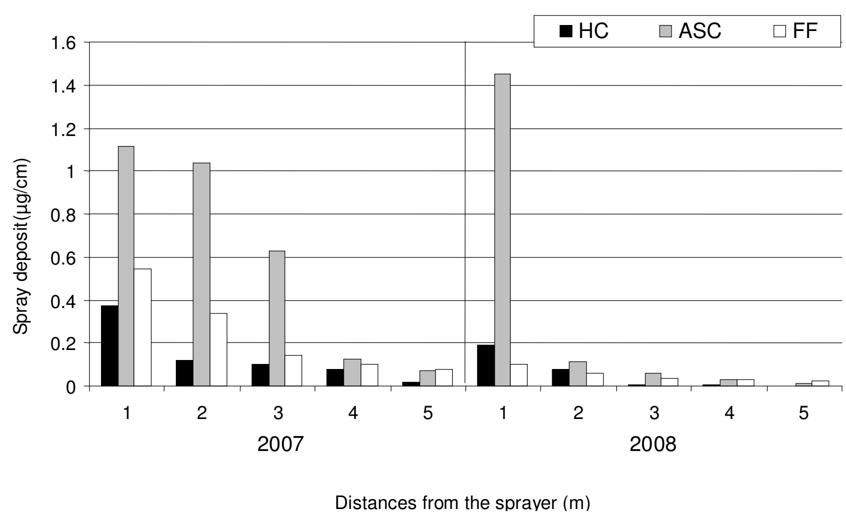

Figure 1. Spray drift in horizontally.

Parameters for pesticide decline of strawberries were shown in Table 8. The equations were used for other parameters such as K_{dec}, R_0, R_p, etc. These parameters led to determination of the consuming day of strawberries following pesticide application. The MRL of dicofol on strawberry fruit was 0.02 mg/kg (EC, 2000). In all experiments when the recommended rate of dicofol was applied, the residue levels were above MRL after approximately 1 day in ASC, 2 days in FF and 4 days in HC (Table 8). On the spraying day in 2007 and 2008, residues on strawberries in all applications were higher than the MRL with 1.74 mg/kg and 7.39 mg/kg for HC, 1.21 mg/kg and 6.14 for FF, and 1.10 and 3.98 for ASC, respectively. When HC were used, residues reached the MRL value in approximately 4 days and 7.5 days after spraying in 2007 and 2008. On the other hand, when ASC and FF were used, their residues reached the MRL value earlier than HC: approximately 1 day for ASC and 2 days for FF in 2007 and, approximately 5 days for ASC and FF in 2008. The residues on strawberries were below

Table 5. Average pesticide deposit on leaf surfaces of strawberry plants.

Pesticide application methods	Average pesticide deposit (µg/cm^2)*	
	2007	2008
Broadcast spraying		
HC	0.777 b	0.726 bc
ASC	0.329 a	0.585 ab
Band spraying		
FF	0.929 b	1.223 c
Control	0.004 a	0.096 a

* Different letters in the same column indicate significant differences (P < 0.05) by Duncan test.

Table 6. Pesticide residues on strawberries following pesticide application (Mean values±SD of four replicates).

Year	Pesticide application methods	Active Ingredient (mg/kg) (Days after treatment)						
		0	1	2	3	4	5	6
2007	Broadcast spraying							
	HC	0.0347±0.000	0.0269±0.005	0.0261±0.002	0.0218±0.008	0.0204±0.002	0.0175±0.007	0.0164±0.003
	ASC	0.0218±0.000	0.0225±0.002	0.0196±0.009	0.0159±0.006	0.0143±0.001	0.0134±0.002	0.0086±0.001
	Band spraying							
	FF	0.0241±0.011	0.0232±0.007	0.0214±0.007	0.0198±0.003	0.0148±0.003	0.0136±0.006	0.0130±0.002
	Untreated control	0.0071±0.001	0.0062±0.001	0.0062±0.001	0.0060±0.001	0.0056±0.001	0.0052±0.002	0.0051±0.001
2008	Broadcast spraying							
	HC	0.1479±0.028	0.1044±0.007	0.0611±0.020	0.0564±0.021	0.0581±0.013	0.0353±0.012	0.0189±0.003
	ASC	0.1228±0.006	0.0812±0.006	0.0618±0.006	0.0412±0.004	0.0280±0.006	0.0148±0.003	0.0055±0.004
	Band spraying							
	FF	0.0797±0.012	0.0592±0.003	0.0489±0.006	0.0348±0.004	0.0266±0.001	0.0184±0.001	0.0069±0.002
	Untreated control	0.0873±0.010	0.0202±0.006	0.0088±0.001	0.0061±0.001	0.0022±0.001	0.0011±0.001	0.0002±0.001

the MRL value in 1 (for ASC), 2 (for FF), and 4 (for HC) days after spraying day in 2007 and, approximately 5 (for ASC and FF) and 7.5 (for HC) days after spraying day in 2008. On the other hand, the MRL of dicofol on strawberry fruit is 1.00 mg/kg and suggested consuming day is 7 days after pesticide application according to WHO and FAO. In this study, the residues on strawberries were below the legal limits (MRL) value (according FAO and WHO) in 1 day after spraying in 2007 and 2008.

When HC, FF, and ASC were used, the suggested consuming days after pesticide application for these nozzles were 4.1 – 7.5 for HC, 2.2 – 5.2 for FF, and 0.9 – 5.1 days for ASC.

Table 7. Average pesticide residues on strawberries.

Pesticide application methods	Average pesticide residues (mg/kg)* Mean±SD	
	2007	2008
Broadcast spraying		
HC	0.0234 ± 0.007 c	0.0689±0.043 d
ASC	0.0166 ± 0.006 b	0.0508±0.039 c
Band spraying		
FF	0.0186 ± 0.006 b	0.0383±0.025 b
Untreated control	0.0059 ± 0.001 a	0.0180±0.029 a

*Means with the same letter are not significantly different at the 5% level of least significant difference.

Table 8. Parameters for pesticide decline of strawberries.

Pesticide application methods	Equation	R^2	K_{dec} (days^{-1})	R_0 (mg/kg)	R_p (mg/kg)	Decline R_0 to R_p (%)	Suggested consuming day after pesticide application according to MRL (0.02)
2007							
Broadcast spraying							
HC	$R = 0.0326.e^{-0.1194t}$	0.97	0.1194	0.0326	0.0159	51.2	4.1
ASC	$R = 0.0226.e^{-0.1353t}$	0.88	0.1353	0.0226	0.0100	55.8	0.9
Band spraying							
FF	$R = 0.0257.e^{-0.1152t}$	0.95	0.1152	0.0257	0.0128	50.2	2.2
2008							
Broadcast spraying							
HC	$R = 0.1905.e^{-0.2997t}$	0.92	0.2997	0.1905	0.0315	83.5	7.5
ASC	$R = 0.2376.e^{-0.4826t}$	0.95	0.4826	0.2376	0.0131	94.5	5.1
Band spraying							
FF	$R = 0.1345.e^{-0.3674t}$	0.92	0.3674	0.1345	0.0148	89	5.2

R: Residue (mg/kg); t: Time (day); R^2: Coefficient of determination; K_{dec}: Decline constant (days^{-1}); R_0: Initial residue (mg/kg); R_p: Residues at pre-harvest interval of pure a.i. (mg/kg).

Therefore, we suggest that strawberries can be harvested after a minimum of 5 days when the spraying was done with HC, and after 5 days with FF and ASC 5 days when the spraying was done with HC, FF and ASC. The results that this study yielded can well be utilized in the cultivation of strawberries in specific, and in other crops and fruits in general.

Biological efficiency

Population trends in abundance of red spider mites were very similar in 2007 and in 2008 with detections of some unimportant fluctuations in plots of different spraying methods and control plots in both years (Figures 2 and 3). Mean numbers of eggs and mobile mites regularly increased at the beginning of first weeks of April in 2007. Their numbers increased up to the highest population densities on same sampling date, May 8, 2007 (Figure 2). In 2008, earlier infestations of red spider mites in all the plots were detected on 24 May and numbers of eggs and MM stage started to increase after March 31 (Figure 3). Their numbers peaked on April 21 or April 28.There was a statistically meaningful difference among the treatments for numbers of both eggs and MM on day 3 after spraying dicofol, with detection of the similar and significantly lower numbers of RSM in HC, ASC and FF compared to numbers found in control plot in 2007 (Table 9) (Egg: $F = 27.909$; d.f. = 3, 156; $P < 0.001$; MM: $F = 27.909$; d.f. = 3, 156; $P < 0.001$). Day 6 and day 10 after spraying, mean numbers of eggs ($F = 20.642$; d.f. = 3, 156, $P < 0.01$ and $F = 6.453$; d.f. = 3, 156, $P < 0.01$, respectively) and MM in

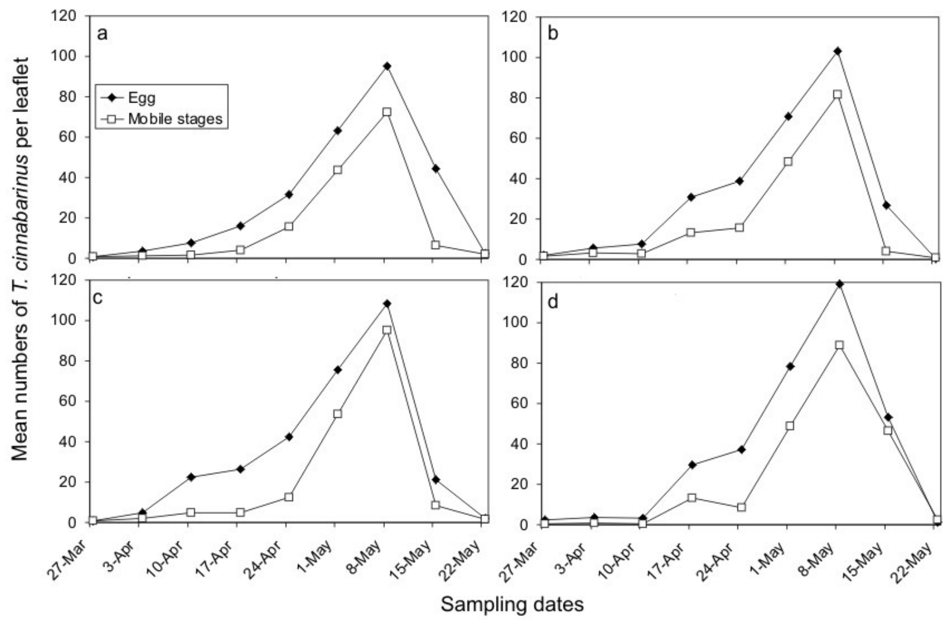

Figure 2. Mean numbers of *T. cinnabarinus* on strawberry leaflets in plots of HC (a) FF (b) ASC (c) and control (d) in 2007.

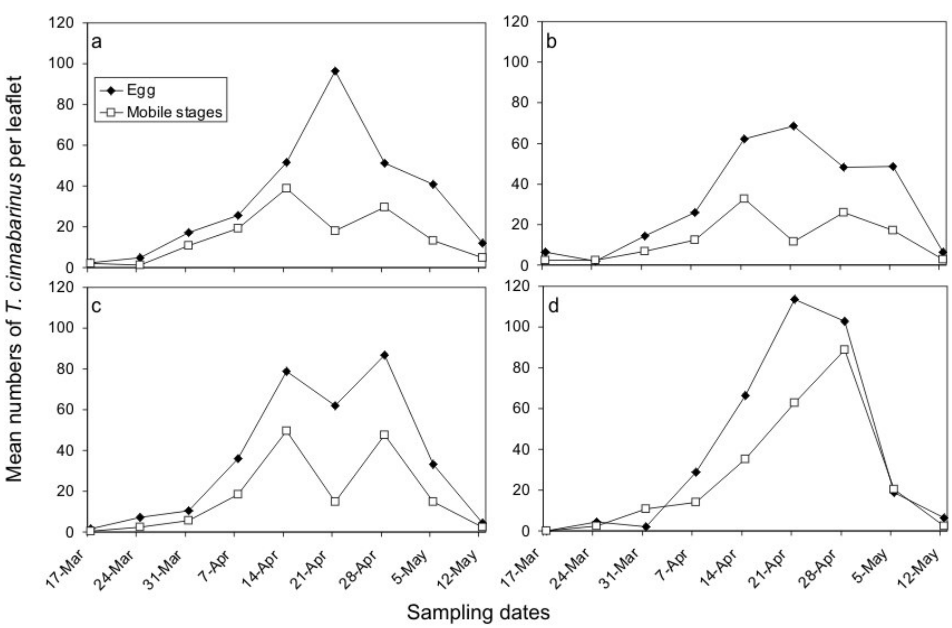

Figure 3. Mean numbers of *T. cinnabarinus* on strawberry leaflets in plots of HC (a) FF (b) ASC (c) and control (d) in 2008.

plots of HC and ASC were similar and significantly larger than FF ($F = 178.292$; d.f. = 3, 156, $P < 0.01$ and $F = 29.318$; d.f. = 3, 156, $P < 0.01$, respectively). The numbers of eggs and mobile stages apparently declined to low levels in all plots and this was probably due to rainfall. On day 14, numbers of red spider mites were lower in plots characterized by the different spraying techniques and also in control plot. However, number of eggs and MM was significantly lower in band spraying than those found in others (Eggs: $F = 2.297$; d.f. 3, 156; $P = 0.033$; MM: $F = 2.207$; d.f. 3, 156; $P = 0.037$, respectively). Similar to previous experimental year, in

Table 9. Results of experiments to control red spider mite, *T. cinnabarinus* Boids., on strawberry plantations, with different acaricides (results before treatment and after applications, 2007)[a].

Treatment	Pre-treatment					Time application (day, date)								
	(8 May)		Day 3 (11 May)			Day 6 (14 May)			Day 10 (18 May)			Day 14 (18 May)		
	MM	E	MM	E	CM	MM	E	CM	MM	E	CM	MM	E	CM
HC	82.2[b]	95.3a	27.7 b	57.3 c	56.3	7.8 b	44.2 a	63.5	9.7 b	8.6 b	61.0	2.0 a	2.4 a	50.0
ASC	90.2	108.3a	38.3 b	93.0 b	44.7	9.4 b	21.2 b	46.4	10.0 b	11.3 b	43.2	1.8 a	2.1 a	47.8
FF	81.5	103.2a	35.2 b	61.3 c	54.5	4.1 c	26.6 b	70.3	1.2 c	4.4 c	83.0	0.8 b	0.6 b	62.0
Control	89.0	106.5a	102.0 a	136.7 a		46.3 a	53.2 a		20.0 a	18.2 a		2.5 a	1.1 ba	

[a] Numbers of mobile mites (MM) or eggs per leaflet, or corrected percentage mortality (CM); [b] means in the same column followed by the same letter do not differ significantly (P < 0.05) by Tukey's honest test.

Table 10. Results of experiments to control red spider mite, *T. cinnabarinus* Boids., on strawberry plantations, with different acaricides (results before treatment and after applications, 2008)[a].

Treatment	Pre-treatment					Time application (day, date)								
	(14 April)		Day 3 (18 April)			Day 6 (21 April)			Day 10 (25 April)			Day 14 (6 May)		
	MM	E	MM	E	CM	MM	E	CM	MM	E	CM	MM	E	CM
HC	38.8a	51.8a	13.7b	65.4b	21.2	17.8b	76.4b	27.4	22.6b	56.1b	51.1	29.6c	51.7b	48.3
ASC	49.6a	78.5a	15.3b	60.6b	36.8	15.7b	65.8b	49.7	29.1b	54.5b	56.4	47.7b	86.8a	28.7
FF	32.5a	62.2a	14.0b	69.0b	22.7	10.2c	48.5c	62.4	14.0c	34.3c	72.7	25.9c	48.3b	56.5
Control	35.0a	66.2a	41.5a	80.9a		62.1a	113.8a		70.4a	129.0a		90.0a	102.8a	

[a] Numbers of mobile mites (MM) or eggs per leaflet, or corrected percentage mortality (CM); [b] means in the same column followed by the same letter do not differ significantly (P < 0.05) by Tukey's honest test.

2008 significantly clear differences in numbers of both eggs and MM among the treatments were found on day 3 (Table 10). Mean numbers of MM in FF were significantly lower than numbers found in HC and ASC treatments and in control on day 6, 10 and 14 (F = 28.193; d.f. 3, 156; P = 0.010; F = 21.280; d.f. 3, 156; P < 0.001 and F = 24.394; d.f. 3, 156; P = 0.001, respectively). Mean numbers of eggs in FF were significantly lower than numbers found in HC and ASC treatments, in control on day 6, 10 and 14 after spraying (F = 3.178; d.f. 3, 156; P = 0.010; F = 6.335; d.f. 3, 156; P < 0.001 and F = 5.547; d.f. 3, 156; P = 0.001, respectively).

Dicofol did not effectively control the RSM populations in two study-years. The corrected mortality rates in band spraying were greater with rates of 70.3 and 83.0% on days 6 and 10 in 2007, respectively. These were followed by the rates of 63.5 and 61.0% obtained in hollow cone treatment on days 6 and 10, respectively. In 2008 the highest corrected mortality rate was obtained in FF with rate of 72.7% on day 10.

Dicofol was not able to suppress the RSM populations effectively in both years. Mortality rates in RSM populations in the plots ranged from 42 to 83% in 2007 and 21 to 72% in 2008. Dicofol had given excellent control of *T. cinnabariuns* on strawberry in the same ecological region of Turkey (Yiğit and Erkılıç, 1992). In this study, it is found that lower efficacy of dicofol in controlling the mite populations is due to a resistance to dicofol. Some previous studies indicated that *T. urticae* developed resistance to dicofol in various crops (Dennehy et al., 1988; Ferguson-Kolmes et al., 1991; Wilson et al., 1995). In Turkey dicofol resistance to *T. cinnabarinus* in cotton has been reported by Dağlı and Tunç (2001).

Mean numbers of eggs and mobile stages (pooled) in band spraying were significantly lower compared to numbers obtained in the treatments of the other two spraying techniques in both years (Tables 9 and 10). HC and ASC were found to be less effective in reducing the population densities of both eggs and MM of RSM. In the present study, it is found that detection of the lower mortality rates in plots of HC and ASC are due to lower deposits of dicofol on the leaf surfaces compared with FF. Different results between this study and previous ones may be related to different factors. In present study, greater spray drifts in horizontally distances were measured from ASC. Smaller drops of <80 µm can cause the spray drifts (Miller, 1993).

Although dicofol did not exhibit desirable control of this pest mite in both years, higher corrected mortality rates of RSM were recorded in the plots of band spraying. Band spraying may effectively reduce the total amount of pesticides used on per hectare basis, which, in turn, reduces costs and minimizes the potential for pesticide carryover, allowing the survival of the arthropods including beneficial insects inhabiting the untargeted area, that is, refugia and field margins. Field margins bearing weedy plants have ecologically important roles in conservation and augmentations of the natural enemies (Welling et al., 1988; Boatman and Wilson, 1988; Boatman, 1994; Denys and Tscharntke, 2002).

Conclusions

1. Both highest pesticide deposits on leaf surfaces and best biological efficiency was obtained from FF nozzles in 2007 and 2008.
2. Average pesticide deposits on upper leaf surfaces were found to be higher than average pesticide deposits on lower leaf surfaces of strawberries in all pesticide application methods in 2007 and 2008.
3. The highest spray drift was obtained from ASC in all pesticide application methods in 2007 and 2008.
4. The highest pesticide deposits on ground were obtained from FF in 2007 and 2008.
5. When HC, FF, and ASC were used, the suggested consuming days after pesticide applications for these nozzles were 4.1 – 7.5 for HC, 2.2 – 5.2 for FF, and 0.9 – 5.1 days for ASC. Therefore, we suggest that strawberries can be harvested after 5 days when the spraying was done with HC, FF and ASC.

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