Project title:	Managing ornamental plants sustainably (MOPS)
Project number:	CP 124
Work package title:	Efficacy of plant protection products against sucking insects – western flower thrips / protected ornamentals
Work package leader:	Jude Bennison, ADAS
Report:	Final report, February 2017
Previous report:	Annual reports 2015 and 2016
Key staff:	Jude Bennison, ADAS Kerry Boardman, ADAS
Location of work:	ADAS Boxworth, Cambs
Date work commenced:	May 2016
Date work completed (or expected completion date):	December 2016

The results and conclusions in this report are based on an investigation conducted over a one-year period. The conditions under which the experiments were carried out and the results have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations.

AUTHENTICATION

We declare that this work was done under our supervision according to the procedures described herein and that the report represents a true and accurate record of the results obtained.

Jude Bennison
Senior Research Entomologist
RSK ADAS Ltd.

JABennison

Signature .... Date 29.1.2017......................................

Report authorised by:

John Atwood
Principle Horticultural Consultant
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Signature Date 27.3.2017…………………………

CONTENTS

GROWERS SUMMARY

Headline

- A novel conventional insecticide and a tank mix of the biopesticides Botanigard WP and Majestik improved control of WFT by the predatory mite *Neoseiulus cucumeris* on verbena.
- On some dates adding the sugars adjuvant Attracker improved control of WFT by the conventional insecticide.

Background and expected deliverables

Western flower thrips (WFT), *Frankliniella occidentalis* is a common pest of many ornamental crops, mainly under protection. Feeding damage by adults and larvae on leaves and petals causes white flecks or patches, which later turn brown and necrotic. In addition to causing direct damage which can make the plants unmarketable, WFT can also transmit tospoviruses including *Tomato spotted wilt virus (*TSWV) and *Impatiens necrotic spot virus* (INSV). These viruses also have a wide ornamental host range and can cause severe damage and plant losses. WFT is resistant to most or all currently approved chemical pesticides on many ornamentals nurseries.

A laboratory experiment tested the efficacy of insecticide and biopesticide products against WFT on a susceptible protected ornamental species under controlled conditions. A subsequent glasshouse experiment tested the potential of the most promising treatments from the laboratory experiment in supplementing WFT control by the predatory mites *Neoseiulus cucumeris* within an IPM programme on a protected ornamental species.

Summary of the work and main conclusions

Laboratory experiment

Materials and methods

Nine treatments including seven plant protection products (Table 1) were tested against western flower thrips (WFT), *Frankliniella occidentalis* on pot chrysanthemum flowers in a laboratory experiment at ADAS Boxworth between July and August 2016. There were seven replicates of each treatment with each replicate consisting of a detached pot chrysanthemum flower with a stem.

The stems of individual flowers were placed in a dampened cube of Oasis® and placed into individual ventilated Perspex boxes. Ten WFT adult females from the ADAS WFT laboratory culture were released into each box. The WFT population was confirmed to be resistant to spinosad (Conserve) in a laboratory test in May 2014 and is likely to be resistant to most other insecticides currently approved for use on protected ornamentals. This is typical of WFT on most commercial ornamentals nurseries.

Table 1. Products tested in the laboratory experiment

MOPS code number/active ingredient	Biopesticide or conventional pesticide
Water control	-
Actara (thiamethoxam) – positive control	conventional
130 (azadirachtin)	biopesticide
179 (orange oil)	biopesticide
201 (Met52 OD)	biopesticide
200	conventional
200 tank mixed with fructose, sucrose & saccharose (Attracker)	conventional plus adjuvant
62 (terpenoid blend)	conventional
Beauveria bassiana (Botanigard WP) tank mixed with maltodextrin (Majestik)	biopesticides

Two hours after adding the WFT the treatments were applied with a hand-held sprayer to give good flower cover, just prior to run-off, equivalent to 600 L/ha. The treatments were applied at the supplier's recommended rates and spray intervals and specific adjuvants were only used when recommended by the suppliers. The treatments were applied twice at 7-day intervals except for orange oil which was applied five times at 3-day intervals and Botanigard WP plus Majestik which was applied three times at 5-day intervals. The boxes were kept in a controlled temperature laboratory at 21°C and a 16-hour photoperiod. Numbers of WFT adults and larvae per flower were assessed 2-3 days, seven and fourteen days after the first treatments.

Results and Conclusions

- At all three assessment dates, Actara significantly increased the proportion of dead WFT adults compared with the water controls, giving means of 11%, 35% and 55% kill after 2-3, 7 and 14 days respectively (Figure 1). N.B Actara was used as the positive control in this experiment but is not appropriate for growers to use for control of WFT on flowering plants as it is subject to the current EC restrictions on use of neonicotinoids i.e. it can only be applied to flowering plants in glasshouses and treated plants may not be put outside until after flowering.
- On the first assessment date 2-3 days after the first treatments, two of the products (code 200 used with or without Attracker) and the tank mix of Botanigard WP and Majestik also significantly increased the proportion of dead WFT adults compared with the water controls and both were as effective as Actara, giving means of 8, 6 and 6% kill respectively.
- Seven days after the first treatments, product 200 used with Attracker was again as effective as Actara, giving a mean of 51% kill of WFT adults. Botanigard WP with Majestik was significantly better than the water control but not as effective as Actara or product 200, giving a mean of 14% kill. Azadirachtin was equally as effective as Botanigard WP with Majestik, giving a mean of 12% kill.
- On the final assessment date 14 days after the first spray, product 200 used with Attracker was again as effective as Actara, giving a mean of 71% kill of WFT adults. The tank mix of Botanigard WP and Majestik was significantly better than the water control but not as effective as Actara or code 200 used with Attracker, giving a mean of 32% kill. Orange oil was as effective as Botanigard plus Majestik, giving a mean of 31% kill.
- Seven days after the first treatments were applied, WFT larvae were also recorded in the flowers. On this date only product 200 with Attracker led to significantly less WFT larvae per flower (mean 0.7) than in the water controls (mean 8.7). Fourteen days after the first treatments were applied, all treatments led to significantly less WFT larvae per flower (means 8.7 to 55.9) than in the water controls (mean 76.3). Again on this date, product 200 with Attracker was the most effective product with a mean of 8.7 larvae per flower.
- Overall the best performing treatment was product 200 with Attracker followed by Botanigard WP plus Majestik and these two treatments were selected for further testing in the glasshouse experiment.

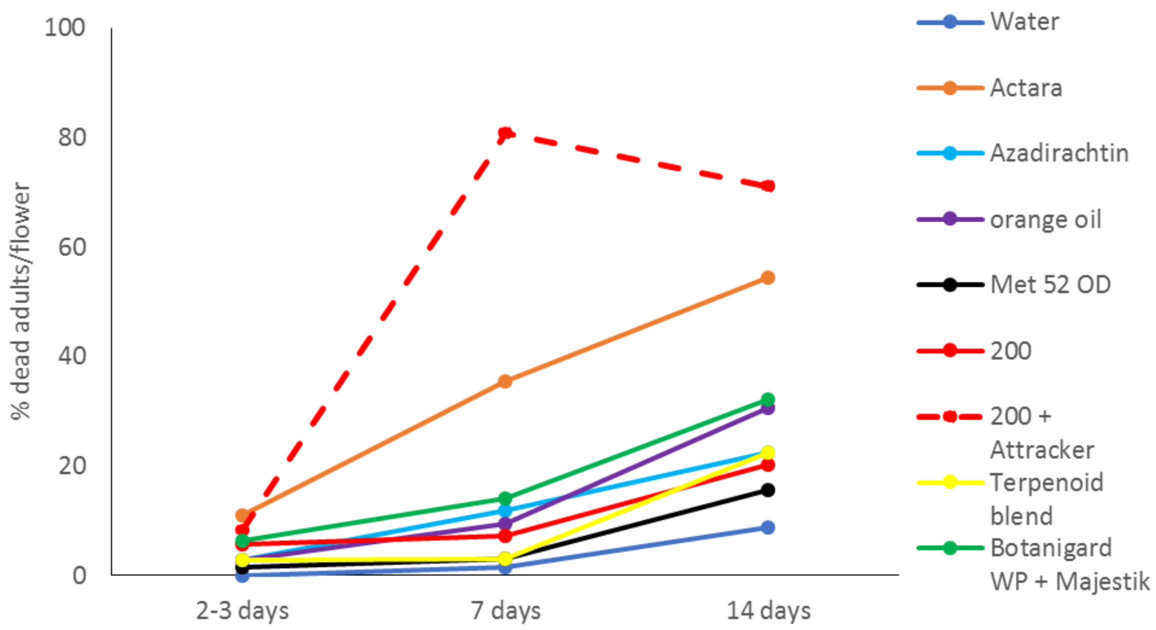


Fig. 1 Mean percentage dead WFT adults 2-3, seven and 14 days after the first treatments in the laboratory experiment

Glasshouse experiment

Materials and methods

Eight treatments (Table 2) were tested against WFT on verbena plants grown in two glasshouse compartments between September and October 2016 at ADAS Boxworth. Each experimental plot was a cage (0.5 x 0.5 x 0.5 m) covered with thrips-proof mesh to avoid WFT adults flying between plots. There were six replicate plots (cages) per treatment. Temperature was regulated in the compartments by venting at 15°C and using insect-screened fans. Plants obtained as plugs were potted on into 9 cm pots on 6 August and kept in thrips-proof cages in a glasshouse until flowering. On 6 September, experimental plants were selected, choosing plants uniform in size, vigour and number of flowers. Four plants were arranged in two rows of two plants in each cage. The cages were stood on capillary matting and watered using sub-irrigation. Twenty WFT adults (18 females and two males) from the ADAS laboratory culture were released into each cage on 6 September.

Table 2. Products tested in the glasshouse experiment

MOPS code number/active ingredient	Biopesticide or conventional pesticide
Water control	-
Neoseiulus cucumeris plus water	-
Neoseiulus cucumeris plus Attracker	adjuvant
Neoseiulus cucumeris plus Actara (positive control)	conventional
Neoseiulus cucumeris plus 200	conventional
Neoseiulus cucumeris plus 200 tank mixed with Attracker	conventional plus adjuvant
Neoseiulus cucumeris plus Botanigard WP tank mixed with Majestik	biopesticides
Neoseiulus cucumeris plus Botanigard WP tank mixed with Majestik plus Attracker	biopesticides plus adjuvant

Five treatments were tested as foliar sprays as supplements to the predatory mite *Neoseiulus cucumeris*, compared with two control treatments (water foliar spray with or without *N. cucumeris*) and the standard treatment Actara. *Neoseiulius cucumeris* were released weekly to all cages except the water control cages at the standard rate of 50/m^2/week from 22 August to 28 September All spray treatments were applied to give good flower and leaf cover, just prior to run-off. . Recommended application rates were used following consultation with suppliers' technical experts. All treatments were applied using an Oxford Precision Sprayer, in 600 litres of water per hectare using 3 bar pressure. The treatments with Botanigard WP were applied using a flat fan nozzle (03F80) as recommended by the suppliers and all other treatments were applied using a hollow cone nozzle (HC/1.74/3). All treatments except those with Botanigard WP were applied at 7-day intervals on 7 and 14 September. The two treatments with Botanigard WP were applied at 5-day intervals on 7, 12 and 17 September.

Numbers of live WFT adults and larvae on all the flowers and leaves in each cage and percentage of flower and leaf damage caused by WFT were recorded one day before the first application and three, six days and 14 days after the first application. Any phytotoxicity was assessed on the same dates. An additional assessment of percentage WFT damage to flowers and the top group of leaves was made 27 days after the first application.

Results and Conclusions

- Three days after the first treatments, all treatments except for the *N. cucumeris* plus water significantly reduced numbers of WFT adults per cage on leaves compared with the water controls but all treatments significantly reduced numbers of WFT adults in flowers and numbers of larvae on leaves. Actara and product 200 with or without Attracker used to supplement *N. cucumeris* led to significantly lower mean numbers of WFT adults on leaves (0.8, 0.2 and 1.5 respectively) than when *N. cucumeris* was used with water (mean 6.7 per cage). Product 200 with Attracker used to supplement *N. cucumeris* was the only treatment that led to significantly lower mean numbers of WFT adults in flowers (mean 2 per cage) compared with when *N. cucumeris* was used with water (mean 7.7 per cage). At this assessment, none of the treatments significantly reduced percentage flower damage but all treatments except for those including Botanigard and Majestik significantly reduced percentage leaf damage compared with the water controls.

- Six days after the first treatments, all treatments significantly reduced numbers of WFT adults and larvae on both leaves and flowers per cage and reduced percentage flower and leaf damage compared with the water controls. Actara, product 200 with or without Attracker and Botanigard WP plus Majestik with or without Attracker used with *N. cucumeris* led to significantly lower mean numbers of WFT adults on leaves (1.0, 0.5, 2.2, 3.3 and 5.3 respectively) than when *N. cucumeris* was used with water (mean 10 per cage). Product 200 plus Attracker was the only treatment used to supplement *N. cucumeris* that significantly reduced percentage leaf damage (5.6%) compared with where *N. cucumeris* was used with water (19.2%).

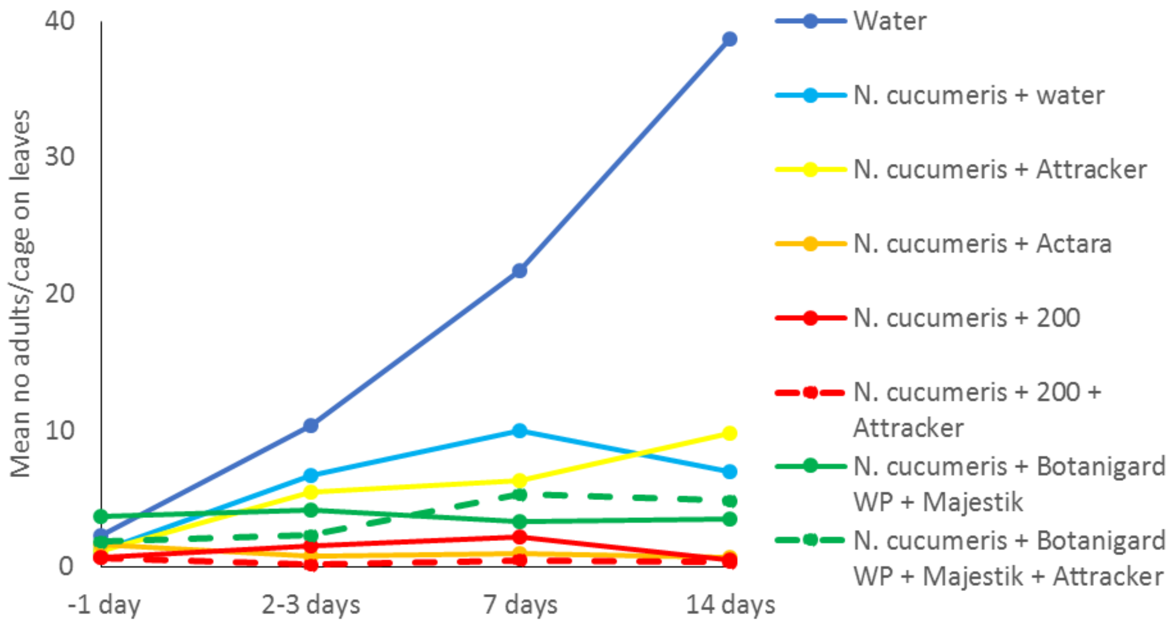


Figure 2. Mean numbers of WFT adults per cage on leaves three, six and 14 days after the first treatments in the glasshouse experiment

- Fourteen days after the first treatments, all treatments significantly reduced numbers of WFT adults and larvae on both leaves and flowers per cage and reduced percentage leaf (but not flower) damage compared with the water controls. Product 200 with or without Attracker and Botanigard WP plus Majestik used with *N. cucumeris* led to significantly lower mean numbers of WFT larvae on leaves (0.2, 1.3 and 3.5 per cage respectively) than when *N. cucumeris* was used with water (mean 20.5 per cage). Actara and product 200 with or without Attracker used with *N. cucumeris* led to significantly less leaf damage (means of 9.8%, 10.4% and 5.9%) than where *N. cucumeris* was used with water (mean 28.5%).

- At the final assessment 27 days after the first treatments, when only flower and leaf damage to the top leaves were assessed, all treatments led to significantly less flower and leaf damage than in the water controls. Actara, product 200 with or without Attracker and Botanigard WP plus Majestik used with *N. cucumeris* led to significantly less leaf (but not flower) damage (means of 4.8, 1.4, 4.2 and 12.1%) than where *N. cucumeris* was used with water (mean of 28.3%).

- Overall the most effective treatment to supplement *N. cucumeris* was product 200 with Attracker. However, product 200 without Attracker and the tank mix of Botanigard WP and Majestik also led to better WFT control on some dates than where *N. cucumeris* was used with a water control. Both these treatments were shown to integrate well with *N. cucumeris* in an IPM programme and have potential for improving WFT control.

Action points

- Although Actara showed efficacy against WFT in these experiments, only use this product on ornamental plants in a glasshouse on plants that will not be moved outside until after flowering. Actara has an EAMU for use on protected ornamentals but is subject to the current EC restrictions on the use of certain neonicotinoids (including thiamethoxam) on plants considered attractive to bees. Actara is not compatible with *Neoseiulus cucumeris*.
- If conventional insecticide 200 gains approval for use on protected ornamentals in the future, consider its use against WFT in IPM programmes as it was at least as effective as Actara and at some assessments its efficacy was improved by adding Attracker. Product 200 has translaminar action which helps to target the pest.
- Botanigard WP and Majestik are already approved so consider using the tank mix in IPM programmes together with predatory mites.

SCIENCE SECTION

Introduction

Various thrips species can damage ornamental plants (Bennison, 2009) but the most problematic species to control is western flower thrips (WFT), *Frankliniella occidentalis* as it is resistant to most or all currently available chemical pesticides (Bielza, 2008). WFT is a widespread and common pest of many ornamental crops, mainly under protection but it can also occur outdoors from spring to autumn. Common protected ornamental, HNS and cut flower host plants include alstroemeria, chrysanthemum, clematis, cyclamen, dahlia, fuchsia, lavatera, lisianthus, primula, and verbena. Feeding damage by adults and larvae on leaves and petals causes white flecks or patches, which later turn brown and necrotic. Feeding in leaf and flower buds can also cause distortion and stunting. In addition to causing direct damage which can make the plants unmarketable, WFT can also transmit tospoviruses including *Tomato spotted wilt virus (*TSWV) and *Impatiens necrotic spot virus* (INSV). These viruses also have a wide ornamental plant host range and can cause severe damage and plant losses. Symptoms include chlorotic or necrotic leaf spots, leaf rings, leaf yellowing and distortion, stem blackening and growing point death (Bennison, 2009; O'Neill & Bennison, 2010).

Due to problems with WFT pesticide resistance, leading growers of protected ornamentals, HNS and cut flowers use biological control methods within IPM programmes. Biological control agents used include predatory mites e.g. the plant-dwelling species *Neoseiulus (Amblyseius) cucumeris* and *Amblyseius swirskii* against thrips larvae on plants, and ground-dwelling species e.g. *Stratiolaelaps scimitus* (formerly known as *Hypoaspis miles*) against the larvae that drop to the ground to pupate. Foliar applications of entomopathogenic nematodes, *Steinernema feltiae* are also used for WFT control by a leading grower of pot chrysanthemums and some other growers of protected ornamentals. Growers using IPM sometimes need to use an IPM-compatible pesticide or biopesticide to supplement these biological control agents, e.g. during the summer months when the crop is flowering, when WFT breed rapidly. There is a need for an effective product to use in these situations and also for use on nurseries where IPM is not currently adopted.

In 2016 a laboratory experiment tested the efficacy of insecticide and biopesticide products against WFT on a susceptible protected ornamental species under controlled conditions. A subsequent glasshouse experiment tested the potential of the most promising treatments from the laboratory experiment in supplementing WFT control by the predatory mites *Neoseiulus cucumeris* within an IPM programme on a protected ornamental species.

Materials and methods – laboratory experiment

Nine treatments including seven plant protection products (Table 1) were tested against western flower thrips (WFT), *Frankliniella occidentalis* on pot chrysanthemum flowers in a laboratory experiment at ADAS Boxworth between July and August 2016 at ADAS Boxworth. There were seven replicates of each treatment with each replicate consisting of a detached pot chrysanthemum flower with a stem. The stems of individual flowers were placed in a dampened cube of Oasis® and placed into individual ventilated Perspex boxes. Ten WFT adult females were released into each box. The WFT population was confirmed to be resistant to spinosad (Conserve) in a laboratory bioassay in May 2014 and is likely to be resistant to most other insecticides currently approved for use on protected ornamentals. This is typical of WFT populations on most commercial nurseries growing protected ornamentals.

Table 1. Products tested in the laboratory experiment

MOPS code number	Active ingredient(s)	Manufacturer	Batch number	% a.i	Formulation type
1. Water (-ve control)	-	-	-	-	-
2. Actara (+ve control)	thiamethoxam	Syngenta	PE-1278KWL4A008	250g/kg (25%)	WG
3. 130	azadirachtin	Trifolio-M	100216Q	1%	EC
4. 179	orange oil	Oro Agri	7964	60g/l	SL
5. 201	*Metarhizium anisopliae* var. *anisopliae* strain F52	Novozymes	1607NFEC03	11%	OD
6. 200	cyantraniliprole	Syngenta	PE-1072SMU6B002	120g/l	WG
7. 200	cyantraniliprole + fructose, glucose & saccharose	Syngenta + Koppert B.V.	PE-1072SMU6B002 + PR17502986	120g/l	WG
8. 62	terpenoid blend	Bayer Crop Science	EZU1425402	16.75%	OD
9. -	*Beauveria bassiana* + maltodextrin	Certis	22WP150703 + 11916	220 g/kg + 598 ml/l	WP + SC

Table 3. Treatments in laboratory experiment

Product name or MOPS code number	Minimum time (days) between applications	Number of applications applied during experiment	Rate of use (product)	Spray volume (l/ha)
1. Water control	-	2	-	600
2. Actara	7	2	0.4 kg/ha (EAMU 0186/2014)	600
3. 130	7	2	0.5% (3.0 L/ha if applied in 600 L of water/ha)	600
4. 179	3	5	0.6% (3.6 L/ha if applied in 600 L of water/ha)	600
5. 201	7	2	1.25 L/ha	600
6. 200	7	2	10g in 100L water	600
7. 200 + Attracker	7	2	10g in 100L water + 0.125% Attracker	600
8. 62	7	2	0.67 v/v (4.0 L/ha if applied in 600 L water/ha)	600
9. Botanigard WP + Majestik	5	3	0.375 kg/ha if applied in 600 L water/ha + 25 ml/L Majestik	600

Two hours after adding the WFT the treatments were applied with a hand-held sprayer to give good flower cover, just prior to run-off, equivalent to 600 L/ha. The treatments were applied at the supplier's recommended rates and spray intervals and specific adjuvants were only used when recommended by the suppliers. Most of the treatments were applied twice at 7-day intervals except for the orange oil which was applied five times at 3-day intervals and the Botanigard WP plus Majestik which was applied three times at 5-day intervals. The boxes were kept in a controlled temperature laboratory at 21°C and a 16-hour photoperiod. Numbers of WFT adults and larvae per flower were assessed three, six and fourteen days after the first treatments. The percentage kill of WFT adults on each assessment date was analysed using Regression Analysis and the numbers of live WFT larvae on the second two assessment dates were subjected to analysis of variance.

Results – laboratory experiment

- At all three assessment dates, Actara significantly increased the proportion of dead WFT adults compared with the water controls, giving means of 11%, 35% and 55% kill after 2-3, 7 and 14 days respectively (Table 4 and Figure 1). N.B Actara was used as the positive control in this experiment but is not appropriate for growers to use for control of WFT on flowering plants as it is subject to the current EC restrictions on use of neonicotinoids i.e. it can only be applied to flowering plants in glasshouses and treated plants may not be put outside until after flowering.
- On the first assessment date three days after the first treatments, two of the products (code 200 used with or without Attracker) and the tank mix of Botanigard WP and Majestik also significantly increased the proportion of dead WFT adults compared with the water controls and both were as effective as Actara, giving means of 8, 6 and 6% kill respectively (Table 4 and Figure 1). Azadirachtin, orange oil, Met52 OD and the terpenoid blend did not increased adult mortality on this date compared with the water controls.
- Seven days after the first treatments, product 200 used with Attracker was again as effective as Actara, giving a mean of 51% kill of WFT adults. Botanigard WP with Majestik was significantly better than the water control but not as effective as Actara or product 200, giving a mean of 14% kill. Azadirachtin was equally as effective as Botanigard WP with Majestik, giving a mean of 12% kill (Table 4 and Figure 1). Azadirachtin, orange oil, Met52 OD and the terpenoid blend did not increased adult mortality on this date compared with the water controls.
- On the final assessment date 14 days after the first spray, product 200 used with Attracker was again as effective as Actara, giving a mean of 71% kill of WFT adults (Table 4 and Figure 1). The tank mix of Botanigard WP and Majestik was significantly better than the water control but not as effective as Actara or code 200 used with Attracker, giving a mean of 32% kill. Orange oil was as effective as Botanigard plus Majestik, giving a mean of 31% kill. Azadirachtin, Met52 OD and the terpenoid blend did not increased adult mortality on this date or either of the previous two dates compared with the water controls.
- Seven days after the first treatments were applied, WFT larvae were also recorded in the flowers. On this date only product 200 with Attracker led to significantly less WFT larvae per flower (mean 0.7) than in the water controls (mean 8.7, Table 5 and Figure 2). Fourteen days after the first treatments were applied, all treatments led to significantly less WFT larvae per

flower (means 8.7 to 55.9) than in the water controls (mean 76.3). Again on this date, product 200 with Attracker was the most effective product with a mean of 8.7 larvae per flower.

- Overall the best performing treatment was product 200 with Attracker followed by Botanigard WP plus Majestik and these two treatments were selected for further testing in the glasshouse experiment.

Table 4. Mean % dead WFT adults per flower in laboratory experiment 2-3, 7 and 14 days after the first treatment. *** significantly fewer than in water controls (P<0.05).** Values sharing the same letters are not significantly different, those with different letters are significantly different.

Treatment	MOPS code	Product	Time interval between applications	No. applications	Mean % dead adults per flower 2-3 days after first treatment	Mean % dead adults per flower 7 days after first treatment	Mean % dead adults per flower 14 days after first treatment
1.	-	water (-ve control)	7	2	0 a	1.46 a	8.86 a
2.	-	thiamethoxam (Actara)	7	2	**11.01 d**	**35.38 d**	**54.45 c**
3.	130	azadirachtin (NeemAzal)	7	2	2.83 ab	11.97 bc	22.48 ab
4.	179	orange oil (PREV-AM)	3	5	2.83 ab	9.49 abc	**30.56 b**
5.	201	*Metarhizium anisopliae (brunneum)* (Met52 OD)	7	2	1.50 ab	3.12 ab	15.56 ab
6.	200	cyantranilipole WG	7	2	**5.59 bcd**	7.23 abc	20.22 ab
7.	200	cyantranilipole WG plus fructose etc (Attracker)	7	2	**8.39 cd**	**50.85 d**	**71.13 c**
8.	62	terpenoids (Requiem)	7	2	2.90 abc	3.14 ab	22.35 ab
9.	-	*Beauveria bassiana* (Botanigard	5	3	**6.40 bcd**	**14.15 c**	**32.20 b**

		WP) plus Majestik					
F value (8 df)					0.017 (P<0.05)	P<0.001	P<0.001

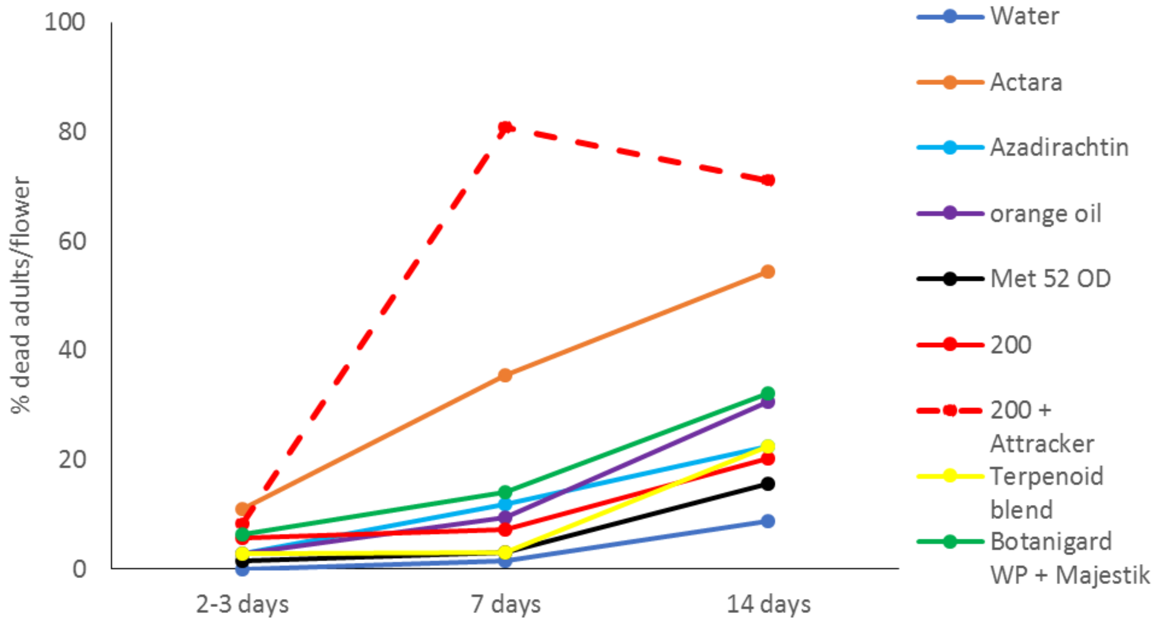


Figure 1. Mean % dead WFT adults per flower in laboratory experiment 2-3, seven and 14 days after the first treatment.

Table 5. Mean numbers of live WFT larvae per flower 2-3, 7 and 14 days after the first treatment. *** significantly fewer than in water controls (P<0.05).** Values sharing the same letters are not significantly different, those with different letters are significantly different.

Treatment	MOPS code	Product	Time interval between applications	No. applications	Mean no. live larvae per flower 7 days after first treatment	Mean no. live larvae per flower 14 days after first treatment
1.	-	water (-ve control)	7	2	8.71 bcd	76.29 d
2.	-	thiamethoxam (Actara)	7	2	5.71 ab	**41.0 b**
3.	130	azadirachtin (NeemAzal)	7	2	12.57 c	**61.29 c**
4.	179	orange oil (PREV-AM)	3	5	15.14 d	**52.71 bc**
5.	201	*Metarhizium anisopliae (brunneum)* (Met52 OD)	7	2	10.86 bc	**55.86 bc**
6.	200	cyantranilipole WG	7	2	4.71 ab	**48.14 bc**
7.	200	cyantranilipole WG plus fructose etc (Attracker)	7	2	**0.71 a**	**8.71 a**
8.	62	terpenoids (Requiem)	7	2	12.57 c	**52.29 bc**
9.	-	*Beauveria bassiana* (Botanigard WP) plus Majestik	5	3	14.0 d	**51.43 bc**
F value (8 df)					P<0.001	P<0.001
LSD					5.940	14.99

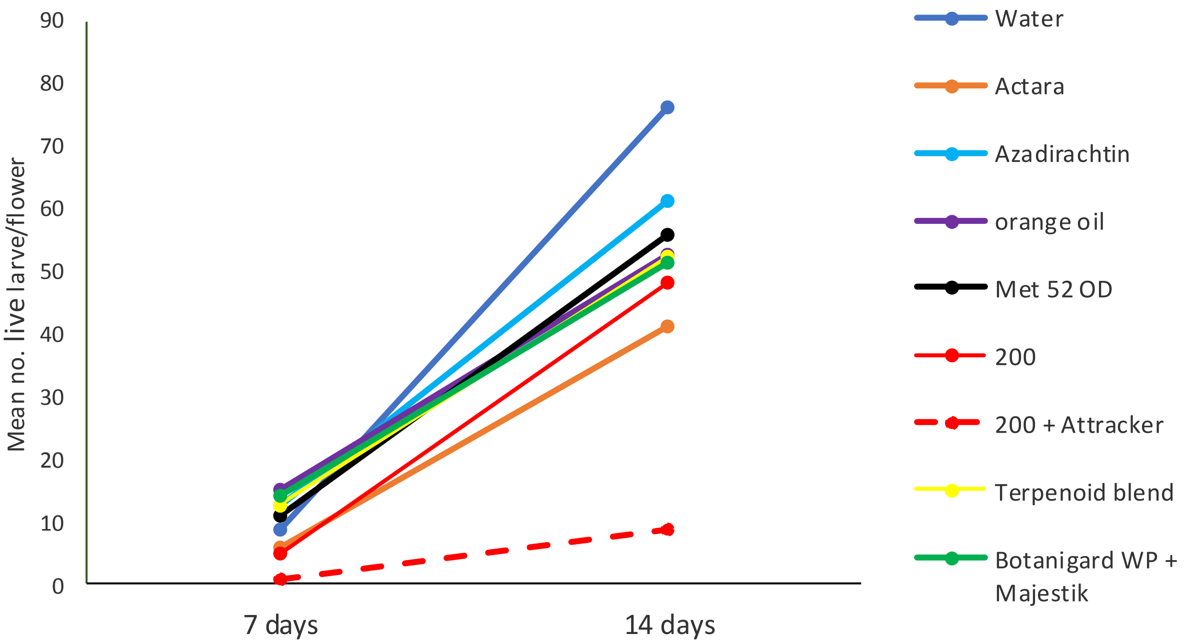


Figure 2. Mean number of live WFT larvae per flower in laboratory experiment 2-3, seven and 14 days after the first treatment.

Materials and methods – glasshouse experiment

Site and crop details

Eight treatments (Table 7) were tested against western flower thrips (WFT), *Frankliniella occidentalis* on verbena (cv. Quartz) plants grown in two glasshouse compartments between September and October 2016 at ADAS Boxworth. The glasshouse compartments were fitted with insect-proof screens to minimize the risk of plants becoming infested with other insect pests. Each experimental plot was a cage (0.5 x 0.5 x 0.5 m) covered with thrips-proof mesh to avoid WFT adults flying between plots. There were six replicate plots (cages) per treatment. Temperature was regulated in the compartments by venting at 15°C and using insect-screened fans.

Plants were obtained as plugs and potted on into 9 cm pots on 6 August. The pots were kept in thrips-proof cages in a glasshouse at ADAS Boxworth until the plants were flowering. On 6 September, plants for the experiment were selected, choosing plants uniform in size, vigour and number of flowers. Four plants were arranged in two rows of two plants in each cage. The cages were stood on capillary matting and watered using sub-irrigation.

Table 6. Test site and plot design information

Test location:	ADAS Boxworth
County	Cambridgeshire
Postcode	CB23 4NN
Soil type/growing medium	Levington M2 compost
Nutrition	-
Crop	Verbena
Cultivar	Quartz
Glasshouse* or Field	Glasshouse
Date of planting/potting	Plugs potted on 6 August 2016
Pot size	9 cm pots
Number of plants per plot	4
Trial design (layout in Appendix C)	Randomised block
Number of replicates	6
Plot size w (m), l (m), total area (m^2)	0.5 x 0.5 x 0.5 m (0.25 m^2), total plot area 12 m^2
Method of statistical analysis	Analysis of variance (ANOVA)

*Temperature and relative humidity settings are given in Appendix B

Target pest(s)

Table 5. Target pest(s)

Common name	Scientific Name	Infestation level pre-application
western flower thrips (WFT)	*Frankliniella occidentalis*	20 adults per cage

Twenty WFT adults (18 females and two males) from the ADAS laboratory culture were released to each cage (plot) on 6 September.

Treatment details

Table 7. Products tested in the glasshouse experiment.

MOPS code number	Active ingredient(s)	Manufacturer	Batch number	% a.i	Formulation type
1.Water (-ve control)	-	-	-	-	-
2. *Neoseiulus cucumeris* + water	-	-	-	-	-
3. *Neoseiulus cucumeris* + Attracker	fructose, glucose & saccharose	Koppert B.V.	+ PR17502986		
4.*Neoseiulus cucumeris* + Actara (+ve control)	thiamethoxam	Syngenta	PE-1278KWL4A008	250g/kg (25%)	WG
5.*Neoseiulus cucumeris* + 200	cyantraniliprole	Syngenta	PE-1072SMU6B002	120g/l	WG
6.*Neoseiulus cucumeris* + 200 + Attracker	cyantraniliprole + fructose, glucose & saccharose	Syngenta + Koppert B.V.	PE-1072SMU6B002 + PR17502986	120g/l + 0.125% Attracker	WG
7.*Neoseiulus cucumeris* + Botanigard WP + Majestik	*Beauveria bassiana* + maltodextrin	Certis	22WP150703 + 11916	220 g/kg + 598 ml/l	WP + SC
8. *Neoseiulus cucumeris* + Botanigard WP + Majestik + Attracker	*Beauveria bassiana* + maltodextrin + fructose, glucose & saccharose	Certis + Koppert B.V.	22WP150703 + 11916 + PR17502986	220 g/kg + 598 ml/l + 0.125% Attracker	WP + SC

Table 8. Treatments in glasshouse experiment

Product name or MOPS code number	**Minimum time (days) between applications**	**Number of applications applied during experiment**	**Rate of use (product)**	**Spray volume (l/ha)**
1.Water control	-	2	-	600
2. *Neoseiulus cucumeris* + water	-	2	-	600
3. *Neoseiulus cucumeris* + Attracker	7	2	0.125%	600
4.*Neoseiulus cucumeris* + Actara (+ve control)	7	2	0.4 kg/ha (EAMU 0186/2014	600
5. 200	7	2	10g in 100L water	600
6.200 + Attracker	7	2	10g in 100L water + 0.125% Attracker	600
7. Botanigard WP + Majestik	5	3	0.375 kg/ha if applied in 600 L water/ha + 25 ml/L Majestik	600
8.Botanigard WP + Majestik + Attracker	5	3	0.375 kg/ha if applied in 600 L water/ha + 25 ml/L Majestik +0.125% Attracker	600

Table 9. Application timing

Application timing	
A1	7 September 2016 (all treatments day 0)
A2	12 September 2016 (Treatments 7 and 8 day 5)
A3	14 September 2016 (Treatments 1-6 day 7)
A4	17 September 2016 (Treatments 7 and 8 day 10)

Table 10. Application details

Application No.	A1 a	A1b	A2	A3	A4
Application date	07/09/16	07/09/16	12/09/16	14/09/16	17/09/16
Time of day	1.10-1.25 pm	2.15-2.50 pm	11.05-11.30am	3.30-4.45 pm	4.25-4.35 pm
Application method	Oxford Precision Sprayer fitted with a 03F80 nozzle, in 600 litres water/ha using 3 bar pressure	Oxford Precision Sprayer fitted with a HC/1.74/3 nozzle, in 600 litres water/ha using 3 bar pressure	Oxford Precision Sprayer fitted with a 03F80 nozzle, in 600 litres water/ha using 3 bar pressure	Oxford Precision Sprayer fitted with a HC/1.74/3 nozzle, in 600 litres water/ha using 3 bar pressure	Oxford Precision Sprayer fitted with a 03F80 nozzle, in 600 litres water/ha using 3 bar pressure
Temperature of air – max/min (°C)	Start: 25.3 Finish: 25.6	Start: 24.7 Finish: 25.5	Start: 25.8 Finish: 27.3	Start: 34.3 Finish: 33.0	Start: 19.1 Finish: 18.5
Relative humidity (%)	Start: 68.1 Finish: 71.0	Start: 71.3 Finish: 69.4	Start: 56.5 Finish: 54.0	Start: 40.2 Finish: 42.9	Start: 75.3 Finish: 79.3
Cloud cover (%)	100	100	50	0	100
Crop growth stage	Flowering	Flowering	Flowering	Flowering	Flowering
Crop comments					
Other*:					

*Includes soil temperature and moisture details where relevant

Five treatments were tested as foliar sprays as supplements to the predatory mite *Neoseiulus cucumeris*, compared with two control treatments and the standard treatment Actara. The controls were a water foliar spray used with or without the use of *N. cucumeris*. *Neoseiulius cucumeris* were released weekly to all cages except the water control cages from 22 August to 28 September at the standard rate of 50/m^2/week. All foliar spray treatments were applied to give good flower and leaf cover, just prior to run-off. Recommended application rates were used following consultation with suppliers' technical experts. All treatments were applied using an Oxford Precision Sprayer, in 600 litres of water per hectare using 3 bar pressure. The treatments including Botanigard WP were applied using a flat fan nozzle (03F80) as recommended by the suppliers and all other treatments were applied using a hollow cone (HC/1.74/3) nozzle. The water volume selected was consistent with the range of water volumes recommended by the suppliers and in consultation with an ADAS spray application expert. All foliar spray treatments except those including Botanigard WP were applied at 7-day intervals over a 2-week period, on 7 and 14 September. The two treatments including Botanigard WP were applied at 5-day intervals on 7, 12 and September.

All treatments were applied to give good flower and leaf cover, just prior to run-off. Recommended application rates were used following consultation with the companies' technical experts. The water volume selected (600 litres per ha) was consistent with the range of water volumes recommended by the suppliers and with ADAS spray application expert, David Talbot. Spray deposition was assessed before the first treatment application by attaching water-sensitive paper to spare verbena plants in pots placed at the same spacing as in the experimental cages (plots). Papers were clipped to the upper and lower surfaces of top, middle and bottom leaves and placed on the floor between the pots.

Assessments

Numbers of WFT on all flowers and leaves per cage and percentage flower and leaf and leaf damage

Numbers of live WFT adults and larvae on all the flowers and leaves in each cage and percentage of flower and leaf damage caused by WFT were recorded one day before the first application and three, six days and 14 days after the first application. Each flower head was tapped onto a small white plastic tray held under the flower head and any thrips dropping onto the tray were recorded, followed by tapping the thrips back onto the assessed flower. Leaf assessments were done by examining the upper and lower surface of each leaf. The assessments were done in-situ using a head-band magnifier, to avoid removing flowers, leaves and thrips from the cages. An additional assessment of percentage WFT damage to flowers and the top group of leaves was made 27 days after the first application.

The following records were made:

- Numbers of live WFT adults and larvae on the flowers and leaves
- Percentage flower head or leaf area with thrips
- Number of flowers

Phytotoxicity

Phytotoxicity scores and photographs of any symptoms were taken at each application date. Records of any observed effects attributable to phytotoxicity were recorded by comparing them to the control plants. Symptoms were scored from 0-9 where 0 was no damage and 9 was where damage was very severe.

Table 11. Assessments

Assessment No.	Date	Growth stage	Timing of assessment relative to last application	Assessment of WFT numbers, WFT damage and phytotoxicity
1	6 September 2016	Flowering	1 day before first application	No. live WFT adults & larvae per flower & leaves, % flower & leaf damage and crop safety
2	9 September 2016	Flowering	3 days after first application (day 3)	As for assessment 1
3	13 September 2016	Flowering	6 days after first application (day 6)	As for assessment 1
4	21 September 2016	Flowering	14 days after first application (day 1	As for assessment 1
5	4 October 2016	Flowering	27 days after first application	% flower & leaf damage

Statistical analysis

The data from each assessment were analysed using analysis of variance (ANOVA) to calculate means, variance and LSDs (P<0.05).

Results

Spray coverage

The application method used achieved good spray coverage of flowers and the upper surface of top and bottom leaves with both nozzles used, although the flat fan nozzle 03F80 used to spray the Botanigard WP and Majestik treatments led to droplet coalescence which was not an ideal (Figures 3 and 4). The hollow cone nozzle HC/1.74/3 gave some coverage on the lower surface of upper and lower leaves but also led to some run-off to the growing media under the leaves (Figure 5).

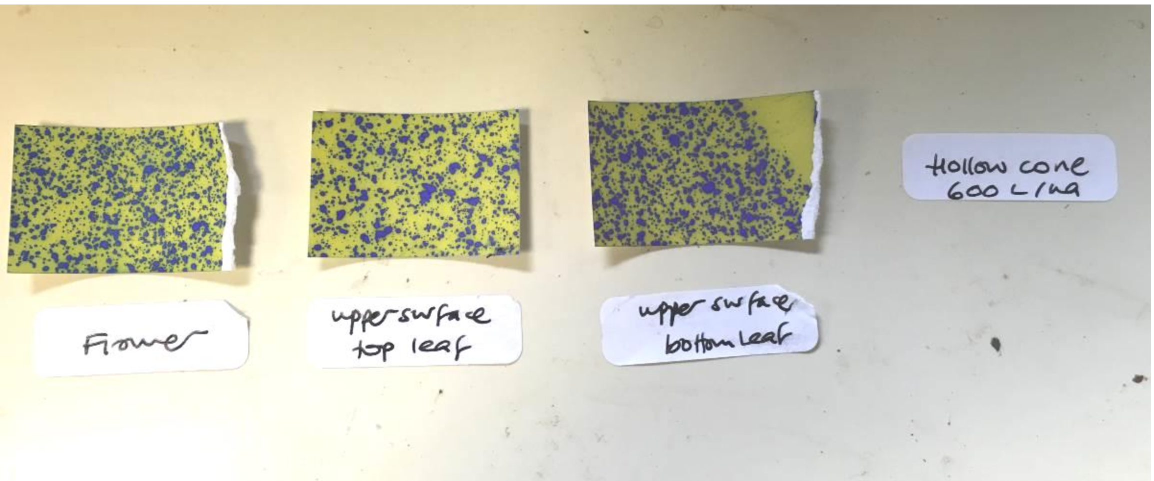


Figure 3. Spray coverage on water-sensitive paper clipped t0 the upper surface of top and bottom leaves and on a flower when sprayed with the hollow cone nozzle HC/1.74/3 used for treatments 1-6.

Figure 4. Spray coverage on water-sensitive paper clipped to the upper surface of top and bottom leaves and on a flower when sprayed with the flat fan nozzle 03F80 used for treatments 7 and 8.

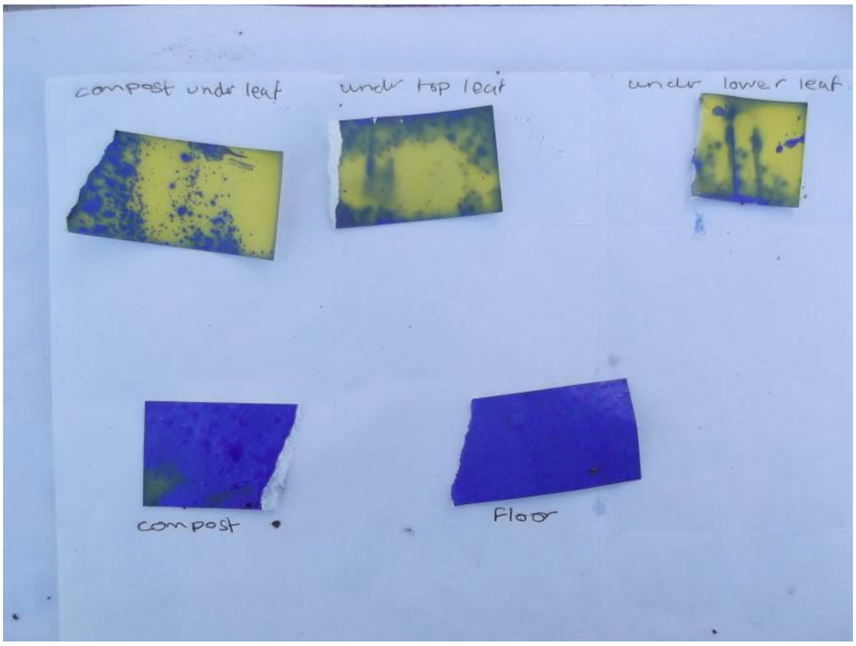


Figure 5. Spray coverage on water-sensitive paper clipped to the upper surface of top and bottom leaves and on a flower when sprayed with the hollow cone nozzle HC/1.74/3 used for treatments 1-6.

Control of WFT

Numbers of WFT adults per cage on leaves

- Mean numbers of WFT adults per cage on leaves in the water controls were 10.3, 21.7 and 38.7 respectively 2-3, 7 and 14 days after the first treatment (Table 12 and Figure 6).
- All treatments except for the *N. cucumeris* plus water significantly reduced mean numbers of WFT adults on leaves 2-3 days after the first treatment compared with the water control.
- The most effective 'knockdown' treatments 2-3 days after the first treatment were *N. cucumeris* plus Actara (0.8 per cage), *N. cucumeris* plus code 200 (1.5 per cage) and *N. cucumeris* plus 200 plus Attracker (0.2 per cage). These three 'knockdown' products were equally effective and were significantly more effective than the *N. cucumeris* plus water control.
- All treatments significantly reduced mean numbers of WFT adults per cage on leaves 7 days after the first treatment compared with the water control.
- The most effective treatments seven days after the first treatment were *N. cucumeris* plus Actara (1 per cage), *N. cucumeris* plus code 200 with or without Attracker (0.5 and 2.2 per cage respectively) and *N. cucumeris* plus Botanigard WP plus Majestik with or without Attracker (5.3 and 3.3 per cage resptectively). These five most effective treatments were equally effective and more effective than the *N. cucumeris* plus water control.
- All treatments significantly reduced mean numbers of WFT adults per cage 14 days after the first treatment compared with the water control but none were more effective than the *N. cucumeris* plus water control.

Table 12. Mean numbers of live WFT adults per cage on leaves 2-3, 7 and 14 days after the first treatment. *** significantly fewer than in water controls (P<0.05).** *** significantly fewer than in water controls plus *Neoseiulus cucumeris* (P<0.05).** Values sharing the same letters are not significantly different, those with different letters are significantly different.

Treatment	MOPS code	Product	Time interval between applications	No. applications	Mean no. adults per cage on leaves 1 day before first treatment	Mean no. adults per cage on leaves 2-3 days after first treatment	Mean no. adults per cage on leaves 7 days after first treatment	Mean no. adults per cage on leaves 14 days after first treatment
1.	-	water (-ve control)	7	2	2.33	10.33 d	21.67 d	38.67 b
2.	-	*N. cucumeris* + water (-ve control)	7	2	1.17	6.67 cd	**10.0 c**	**7.0 a**
3.	-	*N. cucumeris* + Attracker	7	2	1.17	**5.5 bc**	**6.33 bc**	**9.83 a**
4.	-	*N. cucumeris* + Actara	3	5	1.67	**0.83 a**	**1.0 a**	**0.67 a**
5.	50	*N. cucumeris* + 50	7	2	0.67	**1.5 ab**	**2.17 ab**	**0.5 a**
6.	50	*N. cucumeris* + 50 + Attracker	7	2	0.67	**0.17 a**	**0.5 a**	**0.33 a**
7.	-	*N. cucumeris* + Botanigard WP + Majestik	5	3	3.67	**4.17 abc**	**3.33 ab**	**3.5 a**
8.	-	*N. cucumeris* + Botanigard WP + Majestik + Attracker	5	3	1.83	**2.33 abc**	**5.33 ab**	**4.83 a**
F value (7df)					0.486 (P= N.S.)	P<0.001	P<0.001	P<0.001
LSD					2.949	4.119	4.618	9.14

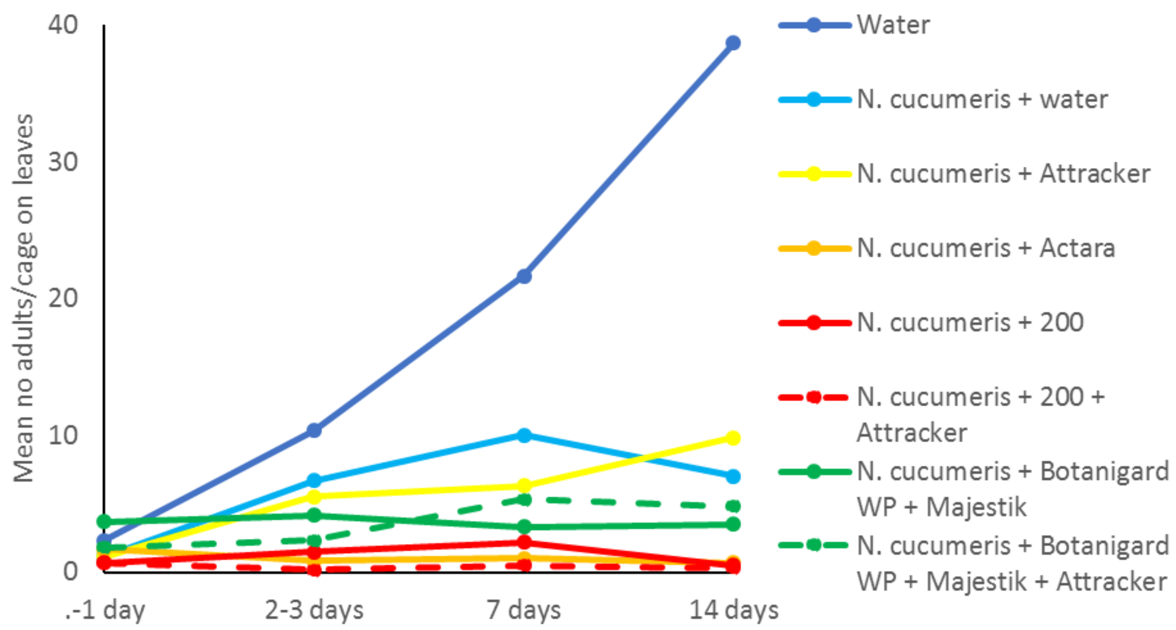


Figure 6. Mean numbers of live WFT adults per cage on leaves 2-3, 7 and 14 days after the first treatment.

Numbers of WFT larvae per cage on leaves

- One day before the first treatments, WFT larvae were recorded on the leaves, which demonstrated that WFT were present on the plants before adults were released to the cages on the same date. Mean numbers of WFT larvae were significantly higher in the water control cages (18.3 per cage) than in all cages except for those treated with Botanigard WP and Majestik (Table 13 and Figure 7). The water control cages had not been receiving releases of *Neoseiulus cucumeris* prior to the first treatments.
- Mean numbers of WFT larvae per cage on leaves in the water controls were 56.5, 109.8 and 112.3 respectively 2-3, 7 and 14 days after the first treatments.
- All treatments reduced numbers of WFT larvae on leaves 2-3 days and 7 days after the first treatments compared with the water control but none of the treatments were more effective than the *N. cucumeris* plus water control (Table 13 and Figure 7).
- Fourteen days after the first treatment, all treatments were more effective than the water control and *N. cucumeris* plus code 200 with or without Attracker and *N. cucumeris* plus Botanigard WP and Majestik were more effective than both the *N. cucumeris* plus water control and plus Actara (Table 13 and Figure 7).

Table 13. Mean numbers of live WFT larvae per cage on leaves 2-3, 7 and 14 days after the first treatment. *** significantly fewer than in water controls (P<0.05).** *** significantly fewer than in water controls plus *Neoseiulus cucumeris* (P<0.05).** Values sharing the same letters are not significantly different, those with different letters are significantly different.

Treatment	MOPS code	Product	Time interval between applications	No. applications	Mean no. larvae per cage on leaves 1 day before first treatment	Mean no. larvae per cage on leaves 2-3 days after first treatment	Mean no. larvae per cage on leaves 7 days after first treatment	Mean no. larvae per cage on leaves 14 days after first treatment
1.	-	water (-ve control)	7	2	18.33 b	56.50 c	109.83 c	112.33 c
2.	-	*N. cucumeris* + water (-ve control)	7	2	**5.17 a**	**7.50 a**	**17.17 ab**	**20.50 b**
3.	-	*N. cucumeris* + Attracker	7	2	**5.50 a**	**10.67 a**	**21.83 ab**	**5.33 ab**
4.	-	*N. cucumeris* + Actara	3	5	**5.50 a**	**0.67 a**	**3.5 ab**	**4.67 ab**
5.	50	*N. cucumeris* + 50	7	2	**2.0 a**	**4.50 a**	**1.83 a**	**1.33 a**
6.	50	*N. cucumeris* + 50 + Attracker	7	2	**1.5 a**	**0.50 a**	**0 a**	**0.17 a**
7.	-	*N. cucumeris* + Botanigard WP + Majestik	5	3	10.83 ab	**28.33 b**	**28.5 b**	**3.5 a**
8.	-	*N. cucumeris* + Botanigard WP + Majestik + Attracker	5	3	10.83 ab	**15.33 ab**	**20.67 ab**	**8.17 ab**
F value (7 df)					0.015 (P<0.05)	P<0.001	P<0.001	P<0.001
LSD					9.35	15.96	22.83	14.85

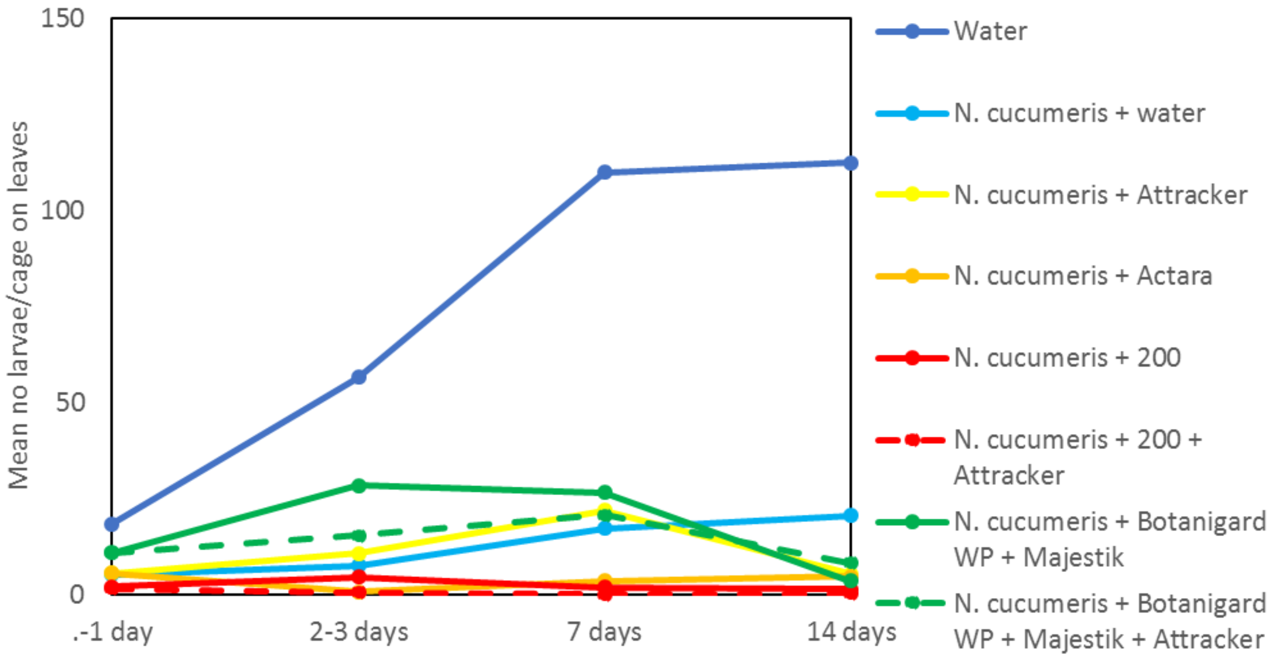


Figure 7. Mean numbers of live WFT larvae per cage on leaves 2-3, 7 and 14 days after the first treatment.

WFT damage to leaves

- As for the numbers of WFT larvae per leaf one day before the first treatments, WFT damage to leaves was recorded on the same date adults were released to the cages. On this date, percentage leaf damage was significantly higher in the cages treated with *N. cucumeris* plus Botanigard WP plus Majestik than in those treated with *N. cucumeris* supplemented with water, Attracker, Actara and product 200 with or without Attracker but equal to that in cages treated with water alone (Table 14 and Figure 8).
- Mean % leaf damage in the water controls was 27.7%, 41% and 80.8% respectively 2-3, seven and 14 days after treatment. An additional assessment of leaf damage to the top leaves only was made 27 days after the first treatment when mean leaf damage had reached 97.6 in the water controls.
- All treatments except for *N. cucumeris* plus Botanigard WP plus Majestik (with or without Attracker) reduced percentage leaf damage 2-3 days after the first treatment compared with the water control but none were more effective than the *N. cucumeris* plus water control.

- Seven days after the first treatment, all treatments were more effective than the water control. *Neoseiulus cucumeris* plus code 200 plus Attracker was the most effective (mean 5.6% leaf damage) and more effective than the *N. cucumeris* plus water control.
- Fourteen days after the first treatment, all treatments were more effective than the water control. *Neoseiulus cucumeris* plus Actara, or plus code 200 with or without Attracker were more effective (mean 9.8, 5.9 and 10.4% leaf damage) than the *N. cucumeris* plus water control.
- On the extra assessment date 27 days after treatment, all treatments were more effective than the water control. *Neoseiulus cucumeris* plus Actara, or plus code 200 with or without Attracker and plus Botanigard WP plus Majestik were more effective than the *N. cucumeris* plus water control (28% leaf damage), with values of 4.8, 4.2, 1.4 and 12.1% leaf damage respectively.

Table 14. Mean % leaf damage one day before treatment and 2-3, 7 and 14 days after the first treatment. *** significantly fewer than in water controls (P<0.05).** *** significantly fewer than in water controls and *Neoseiulus cucumeris* plus water controls (P<0.05).** Values sharing the same letters are not significantly different, those with different letters are significantly different. (N.S.) not significant.

Treatment	MOPS code	Product	Time interval between applications	No. applications	Mean % leaf damage 1 day before first treatment	Mean % leaf damage 2-3 days after first treatment	Mean % leaf damage 7 days after first treatment	Mean % leaf damage 14 days after first treatment	Mean % leaf damage 27 days after treatment (top leaves only)
1.	-	water (-ve control)	7	2	15.0 ab	27.71 c	41.04 d	80.83 c	97.62 d
2.	-	*N. cucumeris* + water (-ve control)	7	2	6.67 a	**14.42 ab**	**19.21 bc**	**28.54 b**	**28.29.c**
3.	-	*N. cucumeris* + Attracker	7	2	6.42 a	**14.83 ab**	**22.83 c**	**29.58 b**	**24.58 bc**
4.	-	*N. cucumeris* + Actara	3	5	5.88 a	**9.17 a**	**8.17 ab**	**9.79 a**	**4.83 a**
5.	50	*N. cucumeris* + 50	7	2	6.42 a	**11.96 ab**	**9.0 ab**	**10.42 a**	**4.17 a**
6.	50	*N. cucumeris* + 50 + Attracker	7	2	6.92 a	**9.62 a**	**5.62 a**	**5.9 a**	**1.38 a**
7.	-	*N. cucumeris* + Botanigard WP + Majestik	5	3	17.71 b	27.08 c	**28.75 cd**	**31.88 b**	**12.08 ab**
8.	-	*N. cucumeris* + Botanigard WP + Majestik + Attracker	5	3	16.12 ab	22.75 bc	**26. 88 c**	**36.88 b**	**17.29 abc**
F value (7df)					0.028 (P<0.05)	0.006 (P<0.05)	P<0.001	P<0.001	P<0.001
LSD					9.14	11.59	12.43	17.83	14.62

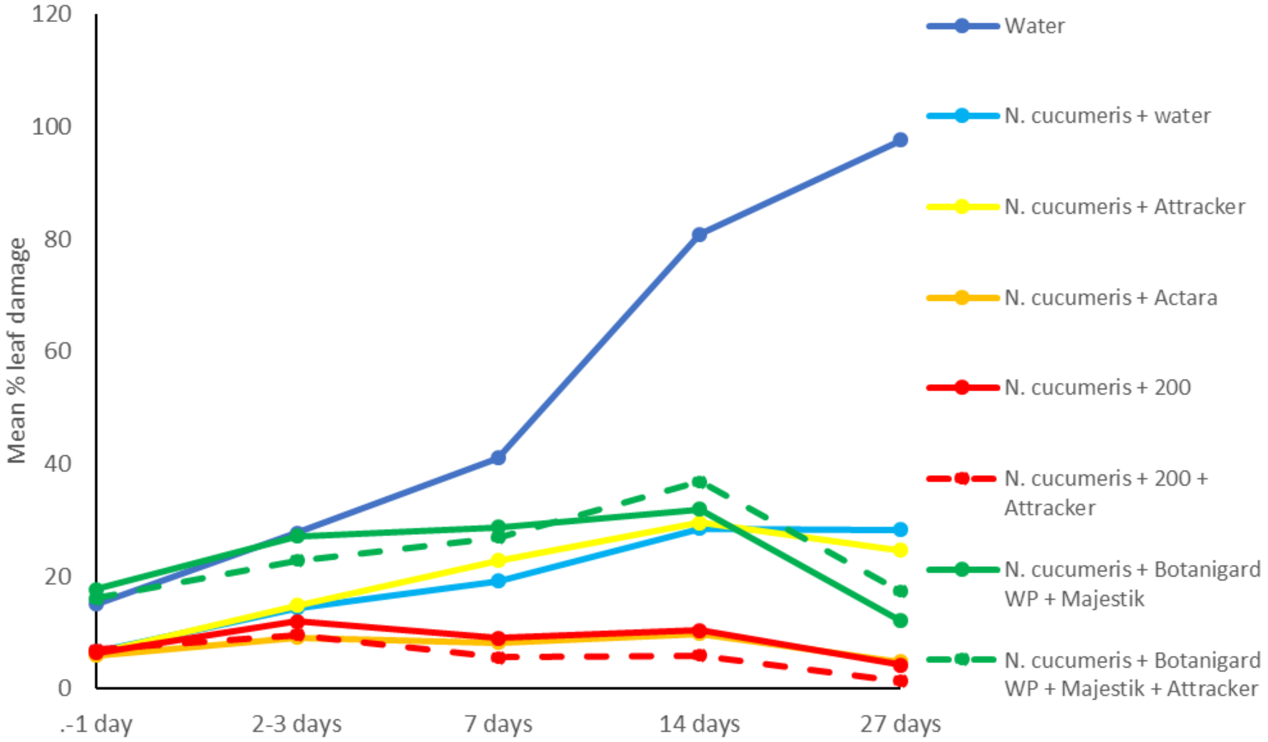


Figure 8. Mean % leaf damage one day before treatment and 2-3, seven and 14 days after the first treatment

Numbers of WFT adults per cage in flowers

- Mean numbers of WFT adults per cage in flowers were 12.8, 11.8 and 18.5 respectively 2-3, seven and 14 days after the first treatments. All treatments reduced numbers of WFT adults compared with the water controls on all dates. The only treatment that was more effective than the *N. cucumeris* plus water control was *N. cucumeris* plus code 200 plus Attracker 2-3 days after the first treatment (mean 2.0 adults per cage), Table 15 and Figure 9.

Table 15. Mean no. WFT adults per cage in flowers one day before treatment and 2-3, 7 and 14 days after the first treatment. *** significantly fewer than in water controls (P<0.05). * significantly fewer than in water controls and *Neoseiulus cucumeris* plus water controls (P<0.05).** Values sharing the same letters are not significantly different, those with different letters are significantly different. (N.S.) not significant.

Treatment	MOPS code	Product	Time interval between applications	No. applications	Mean no. adults per cage in flowers 1 day before first treatment	Mean no. adults per cage in flowers 2-3 days after first treatment	Mean no. adults per cage in flowers 7 days after first treatment	Mean no. adults per cage in flowers 14 days after first treatment
1.	-	water (-ve control)	7	2	0	12.83 c	11.83 c	18.50 b
2.	-	*N. cucumeris* + water (-ve control)	7	2	0	**7.67 b**	**2.67 ab**	**4.83 a**
3.	-	*N. cucumeris* + Attracker	7	2	0	**4.5 ab**	**2.67 ab**	**1.67 a**
4.	-	*N. cucumeris* + Actara	3	5	0.33	**2.17 ab**	**1.83 ab**	**0.67 a**
5.	50	*N. cucumeris* + 50	7	2	0.17	**4.67 ab**	**3.67 ab**	**1.33 a**
6.	50	*N. cucumeris* + 50 + Attracker	7	2	0	**2.0 a**	**1.67 a**	**1.33 a**
7.	-	*N. cucumeris* + Botanigard WP + Majestik	5	3	0.33	**5.67 ab**	**1.50 a**	**2.33 a**
8.	-	*N. cucumeris* + Botanigard WP + Majestik + Attracker	5	3	0	**7.33 ab**	**6.67 b**	**7.5 a**
F value (7df)					0.413 (P=N.S.)	0.002 (P<0.05)	P<0.001	P<0.001
LSD					0.427	4.891	4.379	8.091

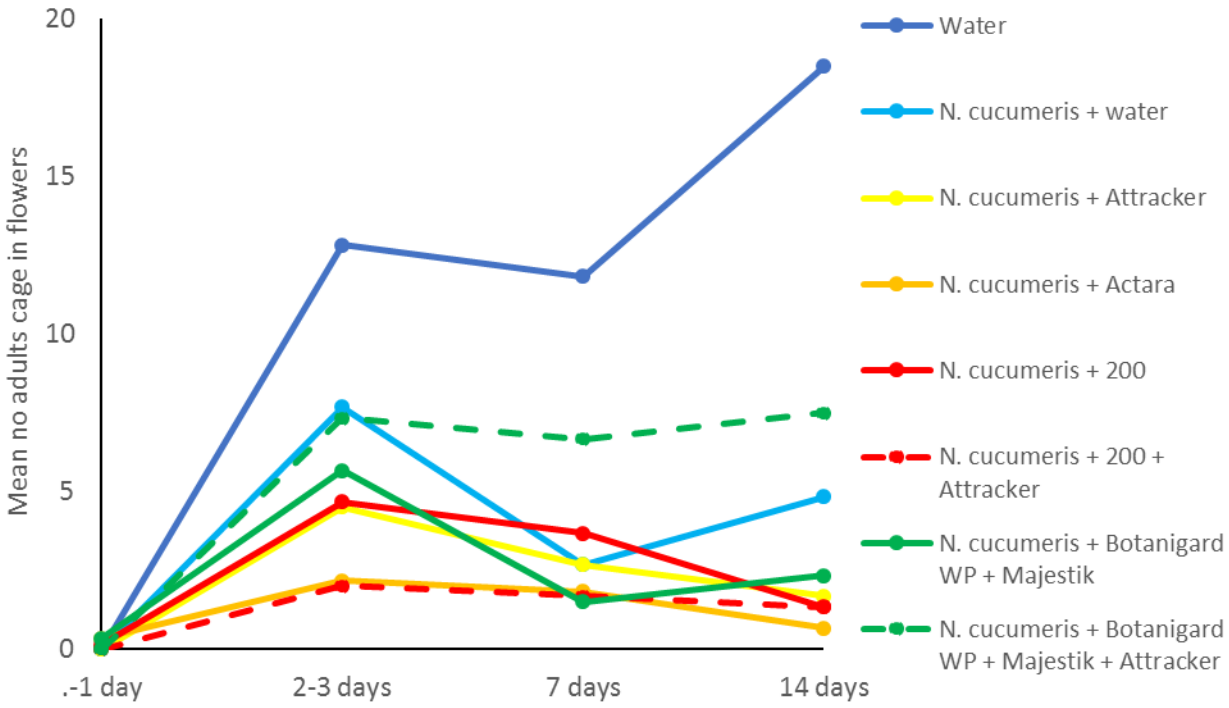


Figure 9. Mean no. WFT adults per cage in flowers one day before treatment and 2-3, seven and 14 days after the first treatment.

Number of WFT larvae per cage in flowers

- Mean numbers of WFT larvae per cage in flowers were 17.7, 19.3 and 27.83 respectively 2-3, 7 and 14 days after the first treatment (Table 16 and Figure 10).
- None of the treatments significantly reduced numbers of WFT larvae 2-3 days after the first treatment compared with any of the controls.
- All treatments reduced numbers of WFT larvae compared with the water controls 7 and 14 days after the first treatment. None of the treatments was more effective than the *N. cucumeris* plus water control.

Table 16. Mean no. WFT larvae per cage in flowers one day before treatment and 2-3, 7 and 14 days after the first treatment. *** significantly fewer than in water controls (P<0.05).** Values sharing the same letters are not significantly different, those with different letters are significantly different. (N.S.) not significant.

Treatment	MOPS code	Product	Time interval between applications	No. applications	Mean no. larvae per cage in flowers 1 day before first treatment	Mean no. larvae per cage in flowers 2-3 days after first treatment	Mean no. larvae per cage in flowers 7 days after first treatment	Mean no. larvae per cage in flowers 14 days after first treatment
1.	-	water (-ve control)	7	2	0	17.70	19.33 b	27 83 b
2.	-	*N. cucumeris* + water (-ve control)	7	2	0.17	6.50	**2.5 a**	**4.0 a**
3.	-	*N. cucumeris* + Attracker	7	2	0	3.80	**1.5 a**	**0.67 a**
4.	-	*N. cucumeris* + Actara	3	5	0.50	7.0	**0.5 a**	**1.67 a**
5.	50	*N. cucumeris* + 50	7	2	0.17	1.70	**1.33 a**	**1.17 a**
6.	50	*N. cucumeris* + 50 + Attracker	7	2	0.17	0.80	**0.33 a**	**0.33 a**
7.	-	*N. cucumeris* + Botanigard WP + Majestik	5	3	0.50	6.0	**5.83 a**	**1.17 a**
8.	-	*N. cucumeris* + Botanigard WP + Majestik + Attracker	5	3	0.33	5.0	**7.17 a**	**1.17 a**
F value (7 df)					0.506 (P= N.S.)	0.066 (P= N.S.)	0.003 (P<0.01)	P<0.001
LSD					0.5937	10.22	9.14	12.04

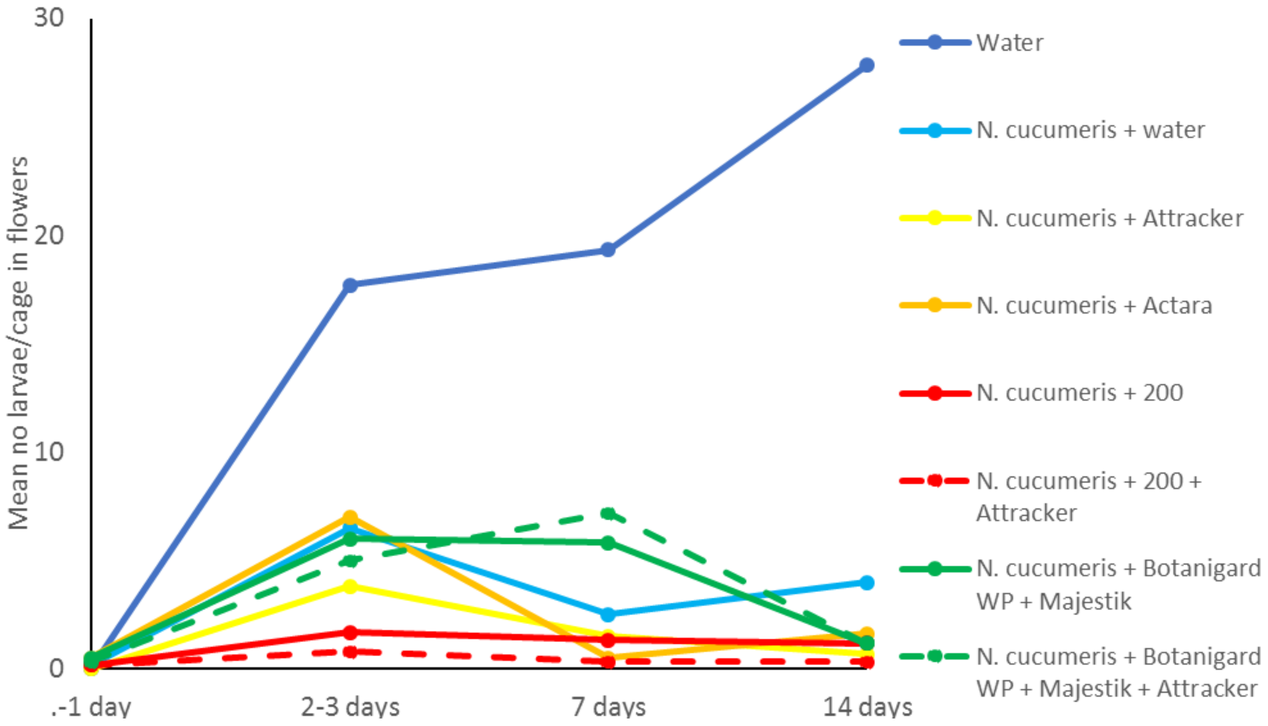


Figure 10. Mean no. WFT larvae per cage in flowers one day before treatment and 2-3, 7 and 14 days after the first treatment.

WFT damage to flowers

- Mean % flower damage (i.e. % of petal area damaged) was 6.5%, 12.1% and 18.3% respectively 2-3, seven and 14 days after the first treatment. An additional assessment was made 27 days after the first treatment, when there was a mean of 27.6% flower damage in the water controls (Table 17 and Figure 11).
- None of the treatments reduced % flower damage 2-3 or 14 days after the first treatment compared with the water controls.
- Seven days after treatment, all treatments reduced % flower damage compared with the water controls and all were equally effective but none were more effective than the *N. cucumeris* plus water control.
- On the extra assessment date 27 days after the first treatment, all treatments reduced % flower damage compared with the water controls but not when compared with the *N. cucumeris* plus water control. All treatments were equally effective.

Table 17. Mean % flower damage one day before treatment and 2-3, 7 and 14 days after the first treatment. *** significantly fewer than in water controls (P<0.05).** Values sharing the same letters are not significantly different, those with different letters are significantly different. (N.S.) not significant.

Treatment	MOPS code	Product	Time interval between applications	No. applications	Mean % flower damage 1 day before first treatment	Mean % flower damage 2-3 days after first treatment	Mean % flower damage 7 days after first treatment	Mean % flower damage 14 days after first treatment	Mean % flower damage 27 days after treatment
1.	-	water (-ve control)	7	2	0.12	6.46	12.08 c	18.30	27.64 b
2.	-	*N. cucumeris* + water (-ve control)	7	2	0.25	4.0	**6.18 ab**	10.20	**3.89 a**
3.	-	*N. cucumeris* + Attracker	7	2	1.25	4.83	**7.92 b**	6.0	**7.85 a**
4.	-	*N. cucumeris* + Actara	3	5	0	3.08	**3.63 a**	4.40	**4.51 a**
5.	50	*N. cucumeris* + 50	7	2	0.08	4.42	**7.15 ab**	5.40	**3.20 a**
6.	50	*N. cucumeris* + 50 + Attracker	7	2	0.08	3.08	**3.67 a**	2.60	**0.08 a**
7.	-	*N. cucumeris* + Botanigard WP + Majestik	5	3	0.17	5.68	**5.56 ab**	5.80	**3.33 a**
8.	-	*N. cucumeris* + Botanigard WP + Majestik + Attracker	5	3	0.29	4.75	**6.21 ab**	15.30	**3.33 a**
F value (7 df)					0.575 (P= N.S.)	0.101 (P= N.S.)	P<0.001	0.052 (P= N.S.)	P<0.001
LSD					1.274	2.454	3.628	10.60	14.10

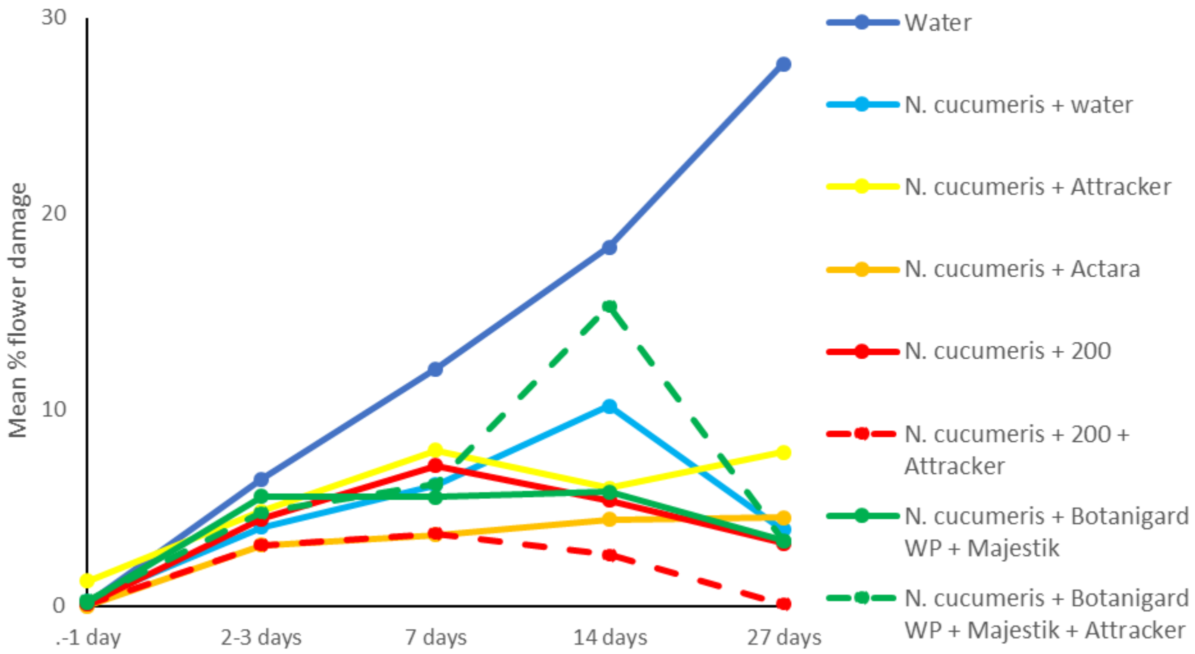


Figure 11. Mean % flower damage one day before treatment and 2-3, seven and 14 days after the first treatment.

Crop damage (phytotoxicity)

No symptoms of phytotoxicity were recorded.

Formulations

No problems were encountered during mixing or application of any of the product formulations under test. The tank mix of Botanigard plus Majestik caused foaming in the spray tank.

Effect on non-targets

No effects on other pests were noted during completion of this experiment.

Discussion

Actara (thiamethoxam) was used as the positive control in both the laboratory and glasshouse experiments as it was considered to be the only currently approved conventional insecticide that might give control of the spinosad-resistant population of WFT used, which is typical of those found on many protected ornamental nurseries. However, Actara, although having an EAMU for use on protected ornamentals for control of WFT, is unlikely to be used by growers of flowering ornamentals as it is subject to the current EU restrictions on the use of neonicotinoids on flowering plants considered to be attractive to bees.

Actara acted as a useful positive control in both the laboratory and glasshouse experiments, giving significant reductions in both numbers of WFT and thrips damage. The laboratory experiment acted as a useful pilot experiment to compare the efficacy of a candidate conventional insecticide (product 200) used with or without the adjuvant Attracker and of five candidate biopesticides. The glasshouse experiment protocol proved to be a useful method to compare the efficacy of the two most effective treatments (product 200 with Attracker and Botanigard WP with Majestik) in the laboratory test, when used in an IPM programme together with the predatory mites *Neoseiulus cucumeris*. As Attracker had significantly improved the efficacy of product 200 in the laboratory test, it was also tested as a tank mix with Botanigard WP plus Majestik in the glasshouse test, compared with using the two products without Attracker.

In the glasshouse experiment, both WFT adults and larvae were recorded on the plants before WFT adults were released to the cages, one day before the first treatments were applied. This demonstrates that the young plants used for the experiment must have been infested with low numbers of WFT when received and that the thrips numbers increased during the weeks before the first treatments were applied on 7 September. It was planned to start releases of *Neoseiulus cucumeris* on 6 August when the plants were potted but releases were delayed by two weeks, starting on 22 August. *Neoseiulus cucumeris* feed only on first instar WFT larvae, not on the second instar larvae or the adults, but by predating young larvae they reduce the numbers of older larvae and adults developing. The delayed release of the predatory mites allowed the WFT to increase before the first treatments were applied. However, by 6 September, one day before the treatments were applied and when 20 WFT adults were released to each cage, numbers of WFT larvae on the leaves were already significantly lower in all the treatments including *N. cucumeris* than in the water controls, except for the treatments including Botanigard with Majestik. The higher infestations of larvae in the cages treated with *N. cucumeris* and Botanigard with Majestik put these treatments at a disadvantage early in the experiment. However, by seven days after the first treatments (following two applications of Botanigard with Majestik at 5-day intervals) this treatment was giving equal control of WFT adults on leaves as *N. cucumeris* with Actara or with product 200 alone or tank mixed with Attracker. By 14 days after the first treatment *N. cucumeris* used with Botanigard plus Majestik was equally effective as *N. cucumeris* used with product 200 with or without Attracker in reducing numbers of WFT larvae on leaves and reducing associated leaf damage.

For best efficacy, Botanigard WP is recommended to be applied at the first sign of the target pest and during the late evening, when temperatures are 15-30°C (optimum 20-30°C) and when relative humidity is greater than 70%. However, Majestik is recommended to be applied during quick drying conditions as it acts by suffocating the target pest. Both products are recommended to be applied to give good crop coverage as they are contact in action. In the glasshouse trial the tank mix of these two products were made on 7, 12 and 17 September in the early afternoon, late morning and late afternoon respectively and when air temperatures in the glasshouse were 25, 26-27 and 18-19°C respectively. Minimum temperatures inside the cages on the application dates were 19, 19.5 and 18.5°C respectively and maximum temperatures were 26.5, 30.5 and 20.5°C (Appendix B). Although the maximum temperature rose to 30.5°C on 12 September, this was still within the range for Botanigard WP as temperatures have to reach 35°C before the fungus may be killed.

Relative humidities (rh) in the glasshouse at the time of application were 68-71%, 54-56% and 75-79% respectively. However, rh inside the cages were higher than in the glasshouse as the thrips-proof mesh covering the cages had very fine apertures. On the dates Botanigard WP and Majestik were applied on 7, 12 and 17 September, mean rh inside the cages were 90%, 92% and 97% respectively, miniumum rh were 75%, 84% and 94% and maximum rh were 95, 97 and 98% respectively (Appendix B). Therefore despite the applications being made during the day, rh% were well above the minimum of 70% for optimal Botanigard WP efficacy. However, as Botanigard WP was applied in a tank mix with Majestik in both the laboratory and glasshouse experiments as recommended by the manufacturer, it is not possible to confirm which of the two products was effective in this experiment, or whether both products contributed some control. Further research is justified to confirm the efficacy of the two products when applied separately against WFT.

The results of spraying water-sensitive paper clipped to the flowers, top and bottom leaves indicated that the application method achieved good coverage on the flowers and upper leaf surfaces and less good coverage on the lower leaf surfaces. When Attracker was tank mixed with product 200 this led to significantly better control of WFT in both the laboratory and glasshouse experiments on some assessment dates. This result indicated that despite product 200 having translaminar action, Attracker increased its efficacy (this sugars product is claimed to encourage WFT to come out from their hiding places in flower buds and young leaf tips and thus be more exposed to insecticide sprays). However, although both Botanigard WP and Majestik are contact in action, there was no evidence that Attracker improved control of WFT when it was used in a tank mix with the two products.

The biopesticides azadirachtin, Met52OD and the terpenoid blend did not give any significant kill of WFT adults in the laboratory test compared with the water control and orange oil gave significant kill on only the final assessment date after five applications had been made at 3-day intervals. However all the biopesticide products gave significant reductions in numbers of WFT larvae developing in the laboratory experiment 14 days after the first treatments. Further work is justified on testing the effect of tank mixing Attracker with these biopesticides to determine whether this could improve their efficacy against either WFT adults or larvae or both life stages.

Conclusions

- The most effective treatment in the laboratory test was code 200 tank mixed with Attracker, which was at least as effective as Actara, followed by Botanigard tank mixed with Majestik.
- In the glasshouse experiment, *Neoseiulus cucumeris* effectively reduced mean numbers of WFT on both flowers and leaves and corresponding WFT damage on flowers and leaves compared with the water control.
- Supplementing *N. cucumeris* with Actara or code 200 (with or without Attracker) or Botanigard plus Majestik gave additional control of WFT adults and larvae on leaves and additional reduction in percentage leaf damage on some assessment dates.
- The only treatment that improved *N. cucumeris* control of WFT in flowers was supplementing the predators with code 200 plus Attracker, 2-3 days after the first treatment. None of the treatments was more effective than *N. cucumeris* alone in reducing flower damage.
- Attracker improved control of WFT adults in flowers by code 200 2-3 days after first treatment and improved control of leaf damage by code 200 seven days after the first treatment. Attracker did not improve control of WFT numbers or reduce thrips damage when used with *N. cucumeris* together with Botanigard plus Majestik.

- Overall *N. cucumeris* plus code 200 tank mixed with Attracker was the most effective treatment in the glasshouse experiment, followed by *N. cucumeris* used with Botanigard WP tank mixed with Majestik. At some assessments both these treatments were at least as effective as Actara and occasionally more effective than Actara.
- The results indicated that code 200 alone or tank mixed with Attracker, and Botanigard WP tank mixed with Majestik have a potential role as a back-up treatment to *N. cucumeris* within an IPM programme.
- No phytotoxicity was recorded with any of the treatments.
- Further work is justified on the efficacy of Botanigard WP and Majestik against WFT when applied as individual products rather than as a tank mix.
- Further work is justified on tank mixing Attracker with the other biopesticides used in the laboratory bioassay and with any additional candidate treatments to test whether it can improve their control of WFT. Any effective treatments should be further tested in a glasshouse experiment within an IPM programme.

References

Bielza P (2008) Insecticide resistance management strategies against the western flower thrips, *Frankliniella occidentalis*. Pest Manag. Sci. **64**, 1131-1138.

Bennison, J. (2009). Thrips control on protected ornamental crops. *HDC Factsheet 14/09.*

O'Neill, T. & Bennison, J. (2010). *Tomato spotted wilt virus* in protected edible crops. *HDC Factsheet 23/10.*

Appendix A – *Study conduct*

ADAS is officially recognised by United Kingdom Chemical Regulations Directorate as competent to carry out efficacy testing. The experiments reported were carried out according the internal ADAS operating procedures

GLP compliance will not be claimed in respect of this study.

Relevant EPPO/CEB guideline(s)		**Variation from EPPO**
PP 1/152(3)	Design and analysis of efficacy evaluation trials	none
PP 1/135(3)	Phytotoxicity assessment	none
PP 1/181(3)	Conduct and reporting of efficacy evaluation trials including GEP	none
PP 1/160(2)	Thrips on glasshouse crops	Size of cages and plants limited the number of plants per plot to four rather than a minimum of 15. Six replicates of each treatment rather than the minimum of four.

There were no significant deviations from the EPPO and national guidelines other than those indicated above

Appendix B – *Meteorological data*

Location of the weather station	On site (ADAS Boxworth)
Distance to the trial site	0 m
Origin of the weather data	Weather station for long term average Data logger for average conditions during the trial

Long-term averages from *location* Boxworth 30 year mean

Month/period	Av temp (ºC)	Min temp (ºC)	Max temp (ºC)	Rainfall (mm)
September				n/a
October				n/a

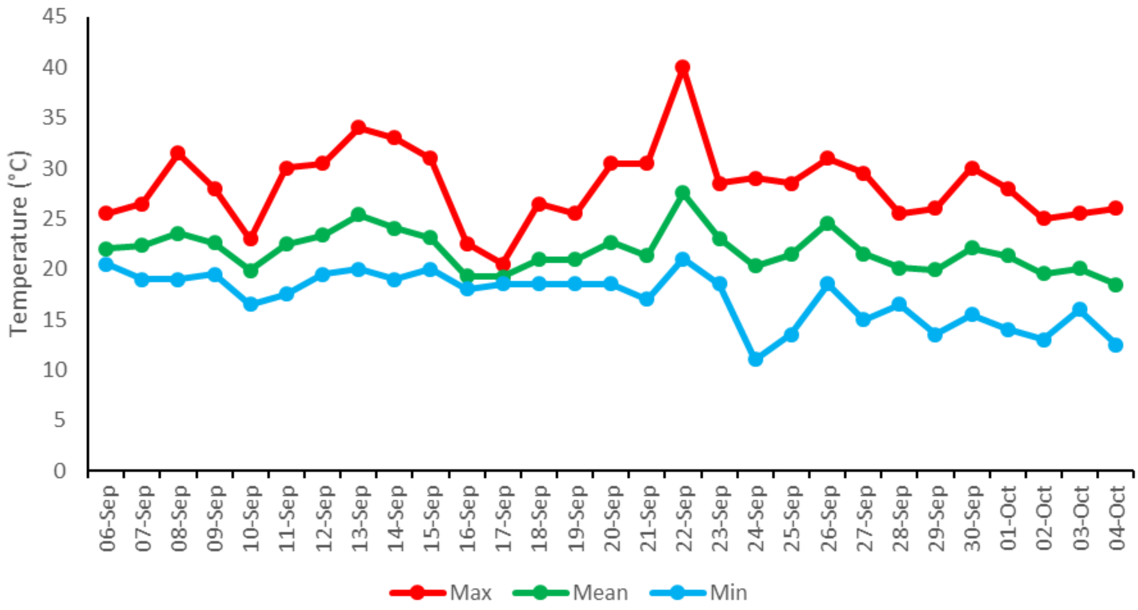
Average conditions during the trial:

Month/period	Av temp (ºC)	Min temp (ºC)	Max temp (ºC)	Av RH (%)*	Rainfall (mm)
Glasshouse 3					n/a
Glasshouse 4					n/a

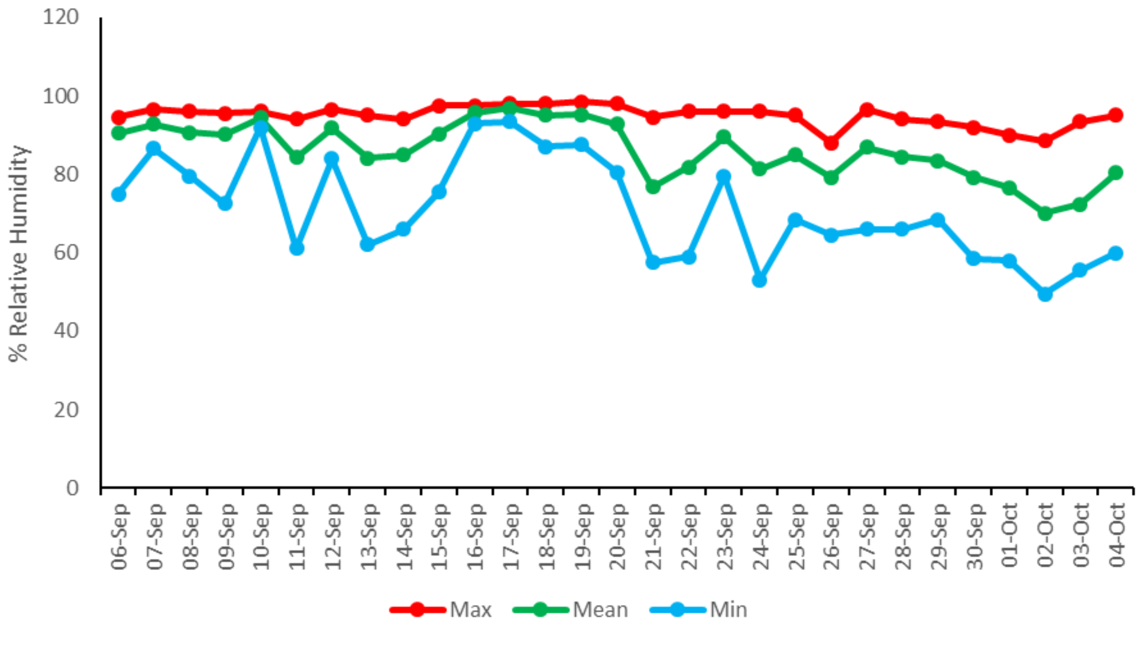
***protected crops only**

Weather at treatment application period (in vestibules of glasshouses 3 and 4):

Month/period	Min temp (ºC)	Max temp (ºC)	Rainfall (mm)
7/9/2016			-
12/9/2016			-
14/9/2016			-
17/9/2016			-



Mean, maximum and minimum temperatures in cages during glasshouse experiment



Mean, maximum and minimum % relative humities in cages during glasshouse experiment

Appendix C – *Agronomic details*

Growing system

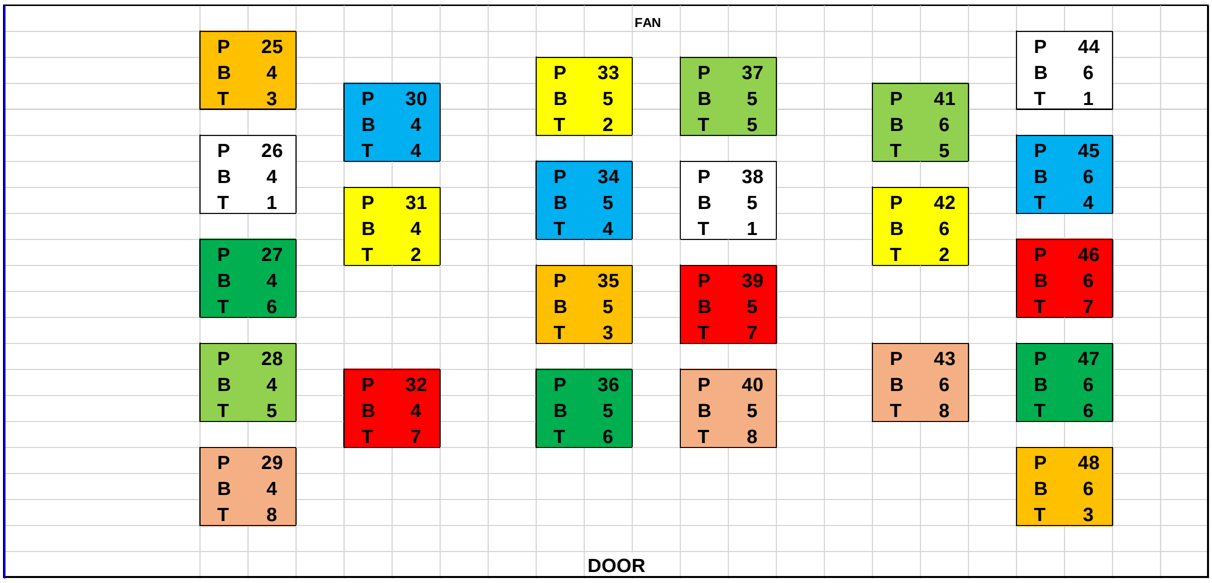
Crop	**Cultivar**	**Planting/sowing date**	**Row width (m) or pot spacing**
Verbena	Quartz	Plug plants potted up on 6 August 2016	9 cm pots arranged in two rows of two

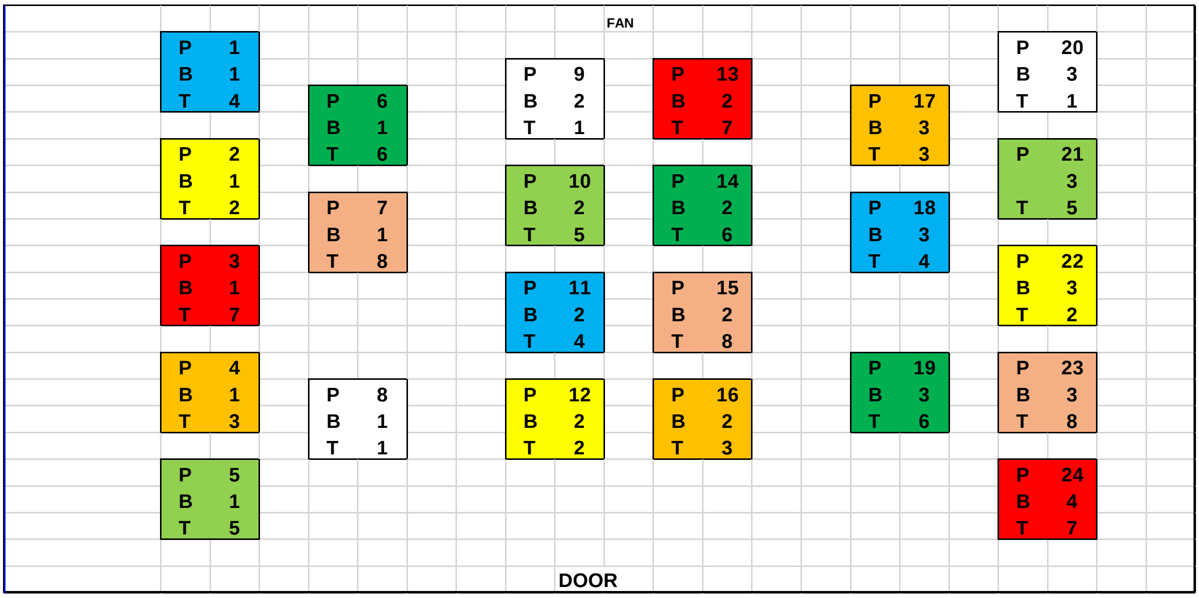
Details of irrigation regime (pot-grown crops)

Type of irrigation system employed (e.g. overhead sprinkler, hand watering, drip, ebb and flow, capillary sandbed or capillary matting)
Drip-irrigation onto capillary matting underneath cages

Appendix D – *Trial layout in glasshouse 3 (top) and 4 (bottom)*

(P = plot, B = block, number 1-8 = treatment number)





Appendix E – *Copy of the Certificate of Official Recognition of Efficacy Testing Facility or Organisation*

Certificate of

Official Recognition of Efficacy Testing Facilities or Organisations in the United Kingdom

This certifies that

ADAS UK Limited

complies with the minimum standards laid down in Regulation (EC) 1107/2009 for efficacy testing.

The above Facility/Organisation has been officially recognised as being competent to carry out efficacy trials/tests in the United Kingdom in the following categories:

Agriculture/Horticulture
Stored Crops
Biologicals and Semiochemicals

Date of issue: 10 May 2013
Effective date: 18 March 2013
Expiry date: 17 March 2018

Certification Number
ORETO 339

Signature
Authorised signatory

HSE
Chemicals Regulation Directorate

Department of
Agriculture and Rural Development

Appendix F – *Photographs*

<table>
<tr><td></td><td></td></tr>
<tr><td>Figure 1. Laboratory bioassay replicate box</td><td>Figure 2. Arrangement of four verbena plants per cage in a replicate plot</td></tr>
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<tr><td></td><td></td></tr>
<tr><td>Figure 3. WFT damage to verbena petals</td><td>Figure 4. WFT damage to verbena leaves</td></tr>
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Figure 5. Dead plants in water control plot at end of experiment	**Figure 6.** Healthy flower in the plots treated with *N. cucumeris* and other experimental treatments at the end of experiment