Project title:	Tomato: Phase 4 of the development of a robust IPM programme for *Tuta absoluta*
Project number:	PC 302d
Project leader:	Mr Paul Howlett, Wight Salads Group Chichester Food Park, Bognor Road, Chichester, West Sussex, PO20 1NW
Report:	Final report, December 2013
Previous report:	Final report, December 2012 (PC 302b)
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Location of project:	Solanum Rigg, Lawford, Essex VHB, Runcton, West Sussex Sandyhill Nursery, Offenham Cross, Wosc WSG, Arreton, Isle of Wight
Industry Representative:	Dr P Morley, (TGA Technical Officer) Studio Cottage, Sandpool Lane, Tarlton Cirencester, GL7 6PD
Date project commenced:	January 2013
Date project completed (or expected completion date):	28 February 2014

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.

Dr R Jacobson
Director
RJC Ltd

Signature .... Date ....

Report authorised by:

Mr P Howlett
Head of Agronomy
Wight Salads Group

Signature .... Date ....

CONTENTS

GROWER SUMMARY

Headline

A new IPM compatible strategy for the control of *Tuta absoluta* in UK tomato crops is given in this report.

Background

Tuta absoluta was first intercepted in the UK on Spanish imports in March 2009 and there soon followed an outbreak in a commercial crop. The pest rapidly became established on several sites across the country where it caused extensive damage by mining in leaves, stems and fruit. UK tomato growers desperately required a reliable method of controlling *T. absoluta* which could be integrated into the existing IPM programme.

The project team has been working towards a robust control programme for *T. absoluta* in conventional and organic crops since the pest's arrival at WSG's production site in Portugal in 2008. Based on experience gained in Mediterranean countries during 2009 and 2010, the team designed a theoretical season-long IPM strategy based on the predatory bug, *Macrolophus* spp. Potential components of this programme were evaluated using a 'modular' approach in which each module was tested independently. The most effective and compatible modules were then brought together for evaluation within this project.

The main components of the programme were:

- *Macrolophus pygmaeus* - a predatory bug
- A product containing spinosad, Product A – an insecticide derived from naturally occurring soil fungi*
- A product containing chlorantraniliprole, Product B - an IPM compatible target specific insecticide*

***These products are only available via a plant health order issued by the FERA Plant Health Inspectors when there is an outbreak of *Tuta absoluta*.**

The intention was to release *Macrolophus* at the start of the growing season in the knowledge that it should begin to provide some control by late spring / early summer. The pest would be allowed to colonise the crop but population growth would be slowed by an application of Product A via the irrigation system before the first generation of caterpillars completed their development. If necessary, Product B would be used as a second line of defence (SLoD) to suppress pest development until the predator gained control. The importance of varying the chemistry used for *T. absoluta* treatments must not be underestimated due to the ever present risk of resistance selection.

Summary

The overall aim of the project was to create a cost-effective and sustainable IPM programme for *T. absoluta* in UK tomato crops. Specific technical objectives were to:

- To evaluate a prototype IPM programme in four 'types' of tomato crops.
- Draft a Factsheet for UK growers describing in detail the new IPM programme.
- Convey results to the tomato industry.

The approach

Four sites were selected for inclusion in the project based on their recent history of *T. absoluta* infestations, their type of growing system and the experience of the nursery staff in participating in large scale experimental trials. The sites included a coir-grown crop, a rockwool-grown crop, a NFT-grown crop and a soil-grown organic crop. *Tuta absoluta* did not become established at the organic site during the first three months of the trial, so the study was switched to a late planted (week 12) soil crop at another site to ensure capture of some data about such crops.

The crops were carefully monitored throughout the 2013 growing season. The nursery staff recorded numbers of adult *T. absoluta* using pheromone traps following a technique developed in HDC Project PC302 and Dr Jacobson visited each site at 2-4 week intervals to record numbers of both *T. absoluta* larvae and *Macrolophus*. Decisions on the timing and type of actions to be taken in each stage of the IPM programme were made in response to the pest monitoring data.

Macrolophus establishment

Where *Macrolophus* was released early in the growing season at the rate of 1/m^2 and then provided with Artemia eggs as supplementary food, the populations began to reach useful levels by mid-May and continued to grow throughout the summer months. By the end of September, there were 6-8 predators per plant head. At the NFT site, where *Macrolophus* was released at lower rates and without supplementary food, population growth was slower. The optimum rates of release and the true benefits of providing supplementary food for *Macrolophus* were beyond the scope of this project and must be investigated in more detail. No *Macrolophus* were released in the soil-grown crop due to the late planting date and there was very little natural colonisation from other sources.

Active mines on plants and timing of insecticidal treatments.

At the coir and rockwool sites, numbers of active mines increased markedly 8-9 weeks post-planting and the first treatment of Product A was deemed necessary after a further 3-4 weeks (*i.e.* late-March / early-April). This provided protection for a further 6-8 weeks when a SLoD treatment was required. In both cases, the speed of the pest development necessitated application via the irrigation system. Thereafter, numbers were suppressed by *M. pygmaeus* and remained at a very low level until the end of the season. No end of season 'clean-up' treatments were required against *T. absoluta*.

The situation developed differently in the earlier planted NFT crop. Active mines were found soon after planting and the first Product A treatment was applied 4 weeks later (mid-January). This provided protection for 16 weeks (*i.e.* until mid-May) when a SLoD with Product B was applied. In the absence of adequate protection from *Macrolophus*, another SLoD was required after a further 10 weeks (mid-July). The speed of the pest development at that time necessitated application via the irrigation system. Thereafter, the growing *Macrolophus* population suppressed the pest and no further treatment was required at the end of season.

The soil-grown crop was planted later and grown at a lower temperature regime. As a consequence, the first Product A treatment was not required against *T.absoluta* until mid-summer. In the absence of *Macrolophus*, two further SLoD treatments were required at intervals of 4-5 weeks. The first was Product A via the irrigation system in late July. The second was a high volume spray of Product B which doubled as the end of season 'clean-up'.

It was clear that the protection afforded by Product A when applied via the irrigation to soil-grown crops was 2-3 weeks less than when applied by the same method to coir-, rockwool- or NFT-grown crops.

Compatibility of spinosad and Macrolophus

Spinosad has been shown to have some detrimental effect on *Macrolophus* populations when tested in laboratory bioassays. Guido Sterk (IPM Impact, Belgium) has demonstrated 'moderate toxicity' following topical application by spraying, which equates to 50-75% mortality in the bioassays. When applied via the irrigation, he reported the impact to be reduced to 'slight toxicity', which equates to 25-50% mortality. In practice, there are now many documented cases of *Macrolophus* populations continuing to increase in size on commercial tomato crops following both high volume sprays and systemic applications of products containing spinosad. The assessments in the present trials reaffirm those observations.

In summary

The IPM programme was highly successful at both the coir and rockwool sites. At the NFT site, *Macrolophus* population growth was slower and as a consequence an additional SLoD treatment was required. However, no plants were lost due to foliar / stem mining and no fruit were graded out due to caterpillar activity.

Results in the soil-grown crop were less conclusive due to the late planting and lack of *Macrolophus.* However, the various components of the programme have been shown to be independently effective in soil-grown crops. Product A applied via the irrigation reduced the *T. absoluta* numbers although the residual effect on subsequent population growth was 2-3 weeks less than in the other three types of growing system. Product B, as a high volume spray, proved to be an effective SLoD. *Macrolophus* is known to establish on soil-grown organic crops and should colonise the plants as rapidly as on coir and rockwool if introduced at the same rate and provided with supplementary food.

Some further work is required to determine the optimum rates of release of *Macrolophus* and the true value of providing supplementary food for independently.

Financial Benefits

In 2012, *T. absoluta* was considered to be the most important pest of tomato crops in the UK. At one nursery during June-July 2012, 30% of fruit were damaged by the pest and graded out. This represented a loss of approximately £50k per hectare to that grower for that period alone. The project would have provided a x2 payback from that single example.

Action Points

- It is important that growers have accurate topical information upon which to base their decisions throughout the season:
  - Count active *T. absoluta* mines on the plants to provide reliable information about the size of the pest population. The procedure must be tailored to each individual site taking into account the type of crop, size of glasshouse and any other monitoring systems that are already in place.
  - Count *Macrolophus* following the guidelines provided in HDC Factsheet 14/10.

- Release *Macrolophus pygmaeus* at the rate of 1 per m^2 as soon as possible after the plants are brought into the production glasshouse. The provision of supplementary food as *Artemia* feeding stations may aid establishment but this requires further investigation.
- Allow *T. absoluta* to colonise the crop and then apply Product A via the irrigation system before the first caterpillars complete their development. This must be done in conjunction with a Plant Health Order for the control of *T. absoluta and* follow the instructions detailed in the EAMU provided by the FERA Plant Health Inspector. This treatment can be supplemented by physical control methods including deleafing, sticky floor treatments and mass trapping with pheromone and / or light traps. However, it is difficult to quantify the real contribution made by such actions.
- Despite the measures taken to delay *T. absoluta* population growth up to this point, it seems inevitable that at least one SLoD treatment will be required before the predatory bugs start to have a significant impact. It is proposed that Product B be the first choice. This product is completely compatible with *Macrolophus* and introduces different chemistry thus reducing resistance selection pressure. Product B high volume sprays must be done in conjunction with a Plant Health Order for the control of *T. absoluta* and follow the instructions detailed in the EAMU provided by the FERA Plant Health Inspector. In some circumstances, treatment with Product A may have to be repeated.
- Other options for SLoD treatments include entomopathogentic nematodes and *Bacillus thuringiensis*, depending on the type of damage and type of crop. However, this must first be discussed and agreed with Plant Health section of FERA.
- By late-spring, *Macrolophus* should be more numerous and start to suppress the *T. absoluta* population growth by feeding on eggs and larvae. However, careful monitoring is required to determine whether it becomes necessary to apply additional SLoD treatments.
- If monitoring indicates that an end of season ‘clean-up’ treatment is required, then it is suggested that Steward® (indoxacarb) be used as it brings different chemistry to the programme and thus contributes to resistance management.

SCIENCE SECTION

Introduction

Background

Tuta absoluta (Meyrick) was first intercepted in the UK on Spanish imports in March 2009 (Korycinska & Moran, 2009) and there soon followed an outbreak in a commercial crop (Fera, 2009). The pest has since become established on several sites across the country where it has caused extensive damage by mining in leaves, stems and fruit. For example, at one nursery in 2012, 30% of fruit were damaged by *T. absoluta* larvae and graded out during June and July. This represented losses of approx £50k per hectare to that grower for that period alone (Jacobson, 2012). The potential losses from interrupted supplies to supermarkets could be even greater. If larvae are detected inside tomato fruit by retailers, then the produce will be rejected and it is highly likely that further supplies from that source will be put on hold until the grower can provide assurance that the infestation has been completely controlled. It will be very difficult for the grower to find another outlet for that produce at short notice and this could result in very large quantities of produce being dumped. The financial loss could be over £300k per hectare depending on the time of year that the infestation is first detected (Jacobson & Morley, 2010). UK tomato growers desperately required a reliable method of controlling *Tuta absoluta* which could be integrated into the existing IPM programme.

The team at WSG has been working towards a robust control programme for *T. absoluta* in conventional and organic crops since the pest's arrival at their production site in Portugal in 2008. Based on experience gained in Mediterranean countries during 2009 and 2010, a theoretical season-long IPM strategy was designed based on the predatory bug, *Macrolophus* spp. (Jacobson, 2011a & 2011b). Potentially useful components of this programme have since been evaluated using a 'modular' approach in which each module has been tested independently (Jacobson & Morley, 2010; Jacobson, 2012; Jacobson & Howlett, 2012). The most effective and compatible modules have now been brought together to form the proposed IPM programme.

For the purpose of this strategy, the growing season has been divided into four distinct periods. The first period, from planting in December until mid-spring, is the key period for establishing *Macrolophus*. Other methods are employed throughout this period to slow down *T. absoluta* population growth. It is proposed that the pest be allowed to colonise the crop but that Product A, which is derived from naturally occurring soil fungi, be applied via the irrigation system before the first caterpillars complete their development. Trial results in 2012 showed that this treatment can suppress the pest's population growth for over 5 weeks in rockwool-grown crops. The spinosad (product A) treatment can be supplemented by physical control methods including deleafing, sticky floor treatments and mass trapping with pheromone and/or light traps.

The second period is from mid- to late-spring. Despite the measures taken during the first period to delay *T. absoluta* population growth, it seems inevitable that at least one second line of defence (SLoD) treatment will be required before the predatory bugs start to have a significant impact. It is proposed that Product B be the first choice because it is completely compatible with *Macrolophus*. In some circumstances, treatment with Product A may have to be repeated. Other options include entomopathogentic nematodes and *Bacillus thuringiensis*, depending on the type of damage and type of crop.

The third period is from early summer through to early autumn. The predatory bugs should now be more numerous and suppress the *T. absoluta* population growth by feeding on eggs and larvae. However, careful monitoring is required to determine whether it becomes necessary to apply additional SLoD treatments. The fourth period is from early to late autumn when the main objective is to reduce the number of pests that survive to infest the following crop. It is proposed that Steward® (indoxacarb) is used for this treatment because it brings different chemistry to the programme and thus contributes to resistance management.

This IPM programme was ready to be tested in commercial crops as a complete package during the 2013 growing season. Due to the nature of the irrigation treatment, it was considered important to test the programme in the four main types of growing media; *i.e.* coir, rockwool, NFT and soil. The IPM programmes would begin at the start of the growing season and progress would be carefully monitored by nursery staff and Dr Jacobson. The nursery staff would record numbers of adult *T. absoluta* using pheromone traps following the technique developed in HDC Project PC302 (Jacobson & Morley, 2010) and Dr Jacobson would visit each site at 2-4 week intervals throughout the season to monitor numbers of *T. absoluta* larvae and *Macrolophus*. Decisions on the timing and type of actions to be taken in each stage of the IPM programme would be made in response to the pest monitoring data.

Objectives of project PC 302b

The overall aim of the project was to create a cost-effective and sustainable IPM programme for *Tuta absoluta* in UK tomato crops. Specific technical objectives were to:

- To evaluate a prototype IPM programme in four 'types' of tomato crops.
- Draft a Factsheet for UK growers describing in detail the new IPM programme.
- Convey results to tomato industry.

Materials and methods

Four sites were selected for inclusion in the project based on their recent history of *T. absoluta* infestations, their type of growing system and the experience of the nursery staff in participating in large scale experimental trials. The initial choices were as follows:

- Conventional coir production – Mr Peter Bell, Solanum Rigg, Lawford, Essex
- Conventional rockwool production – Mr Colin Bridger, VHB, Runcton, West Sussex
- Conventional NFT production – Mr Rick Holt, R&L Holt, Evesham, Worcestershire
- Soil (Organic) production – Mr Brian Moralee, Wight Salads Group, Isle of Wight

Tuta absoluta did not become established at the organic site on the Isle of Wight during the first three months of the trial. Rather than risk failing to obtain data about soil-grown crops, the trial was switched to a late planted soil crop at Solanum Rigg, Lawford, Essex. Details of the sites are shown in Table 1.

Three delta-style pheromone traps were placed in each glasshouse and checked weekly by nursery staff. Pheromone lures were changed at 5-6 week intervals. The average number of adult male *T. absoluta* moths caught per trap each week was calculated and the figures sent to Dr Jacobson by e-mail. This was accompanied by a brief subjective report of the current pest situation at that site.

Dr Jacobson visited each site at 2-4 week intervals, depending on the urgency indicated by the grower's weekly reports. This amounted to 11, 13, 10 and 7 visits to the coir, rockwool, NFT and soil sites respectively (Table 2). On each occasion, assessments were completed to determine the size of the *T. absoluta* and *Macrolophus* populations. The number and distribution of sample points are indicated in Table 2. Although there was no true replication, the aim was to take into account 'within crop' variation by having very large numbers of sample points.

The *T. absoluta* active mine assessment method was based on a technique originally developed in collaboration with Dr John Fenlon, Warwick University (Jacobson & Howlett, 2012). In summary, the top nine expanded leaves (*i.e.* approx 0.9m of growth) of each head were inspected on each occasion and the numbers of active *T. absoluta* mines recorded. The size of the *T. absoluta* populations could therefore be compared between sample points and changes monitored over time. In addition, other rows were 'walked' to monitor the general level of infestation with particular attention given to the gable ends and corners of the glasshouses (*i.e.* the furthest points from the irrigation manifolds).

The assessment method for *Macrolophus* was based on a technique developed in collaboration with Dr Fenlon in HDC Project PC240 (Jacobson & Morley, 2006 & 2009). The head of every fifth plant was beaten over a white tray and numbers of *Macrolophus* adults and nymphs recorded. This data was then used to calculate the average number of *Macrolophus* per plant on each assessment date.

Table 1. Details of the crops and *Macrolophus* release strategy at the four principal trial sites

	Site			
	Coir (Botanicor)	**Rockwool (Cutilene)**	**NFT**	**Soil (Fine sandy loam)**
Area of crop (m^2)	3,000	16,000	2,700	2,000
Plant arrival date	Week 2, 2013	Week 3, 2013	Week 50, 2012	Week 12, 2013
Cultivar	Angelle	Mecano & Amiroso	Encore	Angelle
***Macrolophus* release**	$1/m^2$ Week 6	$1/m^2$ Week 8	$0.25/m^2$ Week 7	Natural infestation
Food *provided* for *Macrolophus* ?	Yes	Yes	No	No

Decisions relating to the choice and timing of insecticidal treatments were based on topical pest monitoring data and were taken after discussion with the grower at that site (Table 3). Each decision took into account the current workload of the nursery staff as well as the harvesting regime and harvest interval of the products. Further explanation is included in the 'Results and Discussion' section of this report. All Product A irrigation treatments and Product B high volume sprays were done in conjunction with a Plant Health Order for the control of *T. absoluta* and followed the instructions detailed in the EAMUs provided by the Plant Health Inspector.

Table 2. Summary of sample points and assessment dates at each site

Type of assessment	Number of:	Site			
		Coir	**Rockwool**	**NFT**	**Soil**
Active mines	Rows included	6	6	5	8
	Plots per row	4	4	4	3
	Plant heads per plot	14	17.5	11	8
	Total number of heads sampled	336	420	220	192
Macrolophus	Rows included	6	6	5	8
	Plant heads sampled per row	22	68	24	10
	Total number of heads sampled	132	408	120	80
Assessments completed in week numbers (2013):		3,5,9,14,18,23, 27,32,36,40,43	5,7,9,10,14,17, 20,24,28,30,33, 37,40	1,3,7,11,16,18, 21,25,29,33	24,28,30,33, 35,37,40

Table 3. Insecticidal treatments applied against *Tuta absoluta* at the four sites during 2013

Site	Treatments applied:	
	Product A via irrigation	**Product B via high volume spray**
Coir	Weeks 14 & 21	-
Rockwool	Weeks 14 & 23	-
NFT	Weeks 2 & 28	Week 18
Soil	Weeks 28 & 33	Week 37

Results and Discussion

The numbers of male *T. absoluta* moths caught in pheromone traps, the numbers of active *T. absoluta* mines on plants and the numbers of *Macrolophus* on plants in the coir-, rockwool-, NFT- and soil-grown crops are summarised in Figures 1, 2, 3 and 4 respectively.

Mean numbers of adult moths on traps.

The mean number of male moths caught per trap fluctuated throughout the season at all four sites. The size of the catch was influenced not only by the size of the *T. absoluta* population but also by day length and weather conditions which both affect the pest's activity patterns. Furthermore, the performance of the traps is always affected by the age of the pheromone lure with attraction gradual declining over the six week period (Jacobson & Morley, 2010). As a consequence, the results obtained from the trapping exercise are never as reliable as the counts of active mines on plants and must be interpreted with caution. Nonetheless, the trap catches did provide useful data. They clearly demonstrated that adult moths were present at all sites throughout the whole growing season; even when numbers of active mines on plants were very small. From this information, it may be inferred that egg laying was continuous and all the crops remained under constant threat from the pest.

Macrolophus establishment

A 'spin-off' study (HDC Project PC 302c) from this series of projects has helped to clarify certain anomalies relating to the taxonomy of the *Macrolophus* complex of species. These anomolies have caused confusion since the predator was first released in UK tomato crops in the mid-1900s. Studies at a molecular level in PC 302c showed that the species previously reported to be *M. caliginosus* (= *M. melanotoma*) is actually *M. pygmaeus* (Hodgetts & Ostoja-Starzewski, 2012). However, this revelation was simply related to nomenclature and has probably not affected the IPM programmes used in the intervening period. The *Macrolophus* released in this study were confirmed to be *M. pygmaeus* using the same molecular tests.

The population trends were very clear and statistical analysis was not required to demonstrate changes over time. At the coir and rockwool sites, *M. pygmaeus* were released 4-5 weeks post-planting at the rate of 1/m^2. The predators were provided with supplementary feed in the form of *Artemia* eggs. This was a novel treatment instigated by the biocontrol supplier (BCP Certis) and was not a planned part of this project. Although *M. pygmaeus* nymphs could usually be found at the *Artemia* feeding stations, the overall populations on the crops did not noticeably increase for about 11 weeks (*i.e.* early May).

Thereafter, the growth in size of the *M. pygmaeus* populations was similar at both sites and reached 6-8 predators per plant head by week 40.

At the NFT site, the grower released fewer *M. pygmaeus* (0.25/m^2) and did not provide supplementary food because he had always obtained a good natural 'carry-over' from the previous crop. However, population growth was much slower than at the two previously described sites and predator numbers remained very small for 15 weeks (*i.e*. until early June). Thereafter, numbers did increase more rapidly but in mid-August there were still only about half as many as recorded at the other two sites. The crop was then terminated due to impending construction work on site.

No *M. pygmaeus* were released in the soil-grown crop due to the late planting date (week 12) and there was little natural colonisation from other sources. However, this was an exceptional situation and it should not be assumed that *M. pygmaeus* is unable to become established on soil-grown crops. There are many past examples of very large populations of *Macrolophus* spp. developing in organic soil-grown crops (Jacobson & Morley, 2009) even resulting in the predator populations being culled during the summer to avoid damage to tomato trusses (Moralee, Wight Salads Group, Pers. Com., 2013).

In summary, where *M. pygmaeus* was released early in the growing season at the rate of 1/m^2 and then provided with supplementary food, the populations began to reach useful levels by mid-May and continued to increase throughout the summer months. At lower rates and without supplementary food, population growth was slower. The optimum rates of release and the true benefits of providing supplementary food for *M. pygmaeus* were beyond the scope of this project and must be investigated in more detail in the near future.

Active mines on plants and timing of insecticidal treatments.

The population trends and treatment effects were very clear and statistical analysis was not required to demonstrate changes over time. At the coir and rockwool sites, numbers of active mines increased markedly 8-9 weeks post-planting and the first treatment of Product A was deemed necessary after a further 3-4 weeks (*i.e.* late-March / early-April). This provided protection for a further 6-8 weeks when a SLoD treatment was required. In both cases, the speed of the pest development necessitated application via the irrigation system. Thereafter, numbers were suppressed by *M. pygmaeus* and remained at a very low level until the end of the season.

The situation developed differently in the earlier planted NFT crop. Active mines were found soon after planting and the first Product A treatment was applied 4 weeks later (mid-January). However, this provided protection for 16 weeks (*i.e.* to mid-May) when a SLoD with Product B was applied. In the absence of adequate protection from *M. pygmaeus*, another SLoD was required after a further 10 weeks (mid-July); the pest development necessitating application via the irrigation system. Thereafter, the growing *M. pygmaeus* population suppressed the pest and no further treatment was required at the end of season.

The soil-grown crop was planted later, grown at a lower temperature regime and no *Macrolophus* were released. The first Product A treatment was not required against *T. absoluta* until mid-summer. In the absence of *M. pygmaeus*, two further SLoD treatments were required at intervals of 4-5 weeks. The first was Product A via the irrigation system in late July. The second was a high volume spray of Product B which doubled as the end of season 'clean-up'.

Notes on choice of chemical treatments

As planned, the decisions relating to the choice and timing of insecticidal treatments were based on topical pest monitoring data and took into account the current workload of the nursery staff as well as the harvesting regime and harvest interval of the products. Product A was always chosen as the first treatment as this was fundamental to the overall strategy. Product B was the preferred option for the first SLoD treatment because this was of a different chemical group and therefore reduced resistance selection pressure. However, in three situations, the speed of pest development and shortage of available time resulted in the Product A irrigation treatment being repeated. Where *M. pygmaeus* populations did build up to acceptable levels, no end of season insecticidal 'clean-up' was deemed necessary for *T. absoluta.*

The importance of varying the chemistry used for *T. absoluta* treatments must not be underestimated because continuous selection pressure from one chemical group could lead to resistance. For example, following the apparent failure of an overseas spinosad treatment in 2012, a formal resistance test was organised at Rothamsted Research (Jacobson, RJC Ltd, Unpublished data, 2012). That test proved inconclusive but the researchers subjected the *T. absoluta* population to several gradually increasing doses of the insecticide and have now recorded a significant shift to over 100 fold resistance in this strain (Berger & Bass, Rothamsted Research, Pers. Com., 2013). This indicates that a few resistant individuals were present in the original population and they were selected to make the whole population resistant. It is absolutely imperative that repeated selection pressure is avoided in UK tomato crops.

It was noticeable that the protection afforded by Product A when applied via the irrigation to soil-grown crops was 2-3 weeks less than when applied by the same method to coir-, rockwool- or NFT-grown crops.

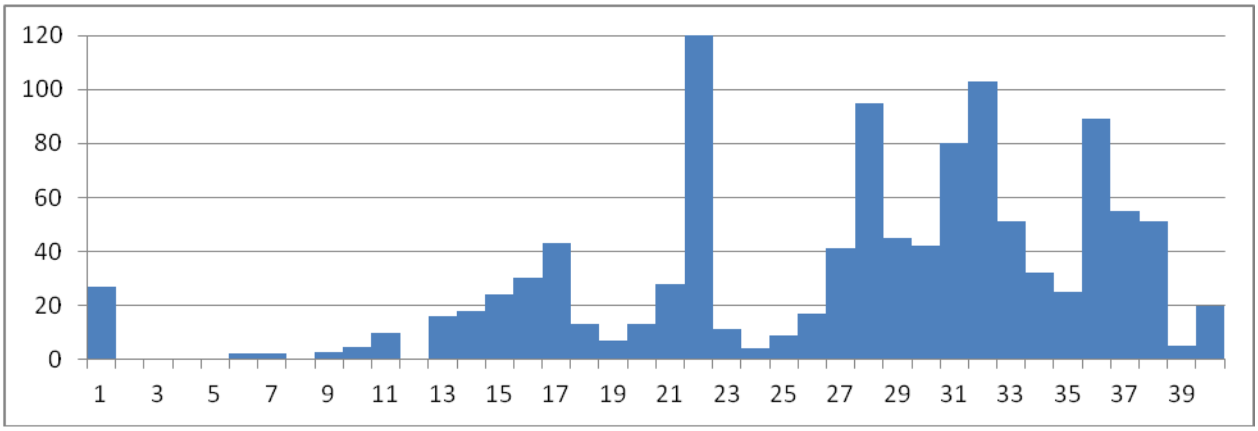
Compatibility of spinosad and Macrolophus

Spinosad is known to have some impact on *Macrolophus* populations when tested in laboratory bioassays. Sterk (IPM Impact, Belgium, Pers. Com., 2012) has demonstrated 'moderate toxicity' following topical application by spraying, which equates to 50-75% mortality in the bioassays. When applied via the irrigation, Sterk reported the impact to be reduced to 'slight toxicity', which equates to 25-50% mortality. In practice, there are now many documented cases of *Macrolophus* populations continuing to increase in size on commercial tomato crops following both high volume sprays and systemic applications of products containing spinosad (*eg* Jacobson & Howlett, 2012). The assessments in the present trials reaffirm those observations.

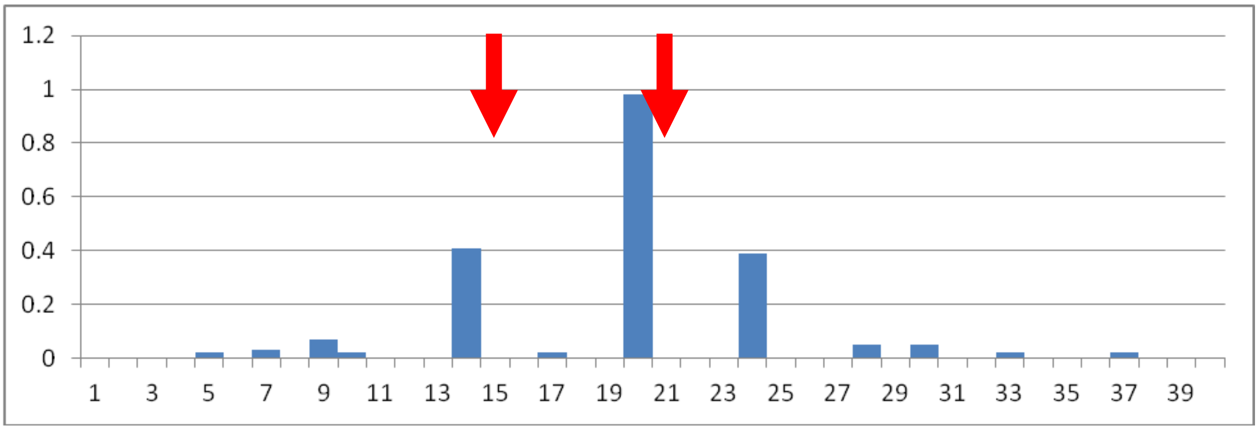
Success of IPM strategy

The IPM programme was highly successful at both the coir and rockwool sites. At the NFT site, *M. pygmaeus* population growth was slower and as a consequence an additional SLoD treatment was required. However, no plants were lost due to foliar / stem mining and no fruit were graded out due to caterpillar activity. Results in the soil-grown crop were less conclusive due to the late planting and lack of *M. pygmaeus.* However, the various components of the programme have been shown to be independently effective. Product A applied via the irrigation reduced the *T. absoluta* numbers although the residual effect on subsequent population growth was 2-3 weeks less than in the other three types of growing system. Product B, as a high volume spray, proved to be an effective SLoD. *Macrolophus* is known to establish on soil-grown organic crops and should colonise the plants as rapidly as on coir and rockwool if introduced at the same rate and provided with supplementary food. Some further work is required to determine the optimum rates of release and the true benefits of providing supplementary food for *M. pygmaeus.*

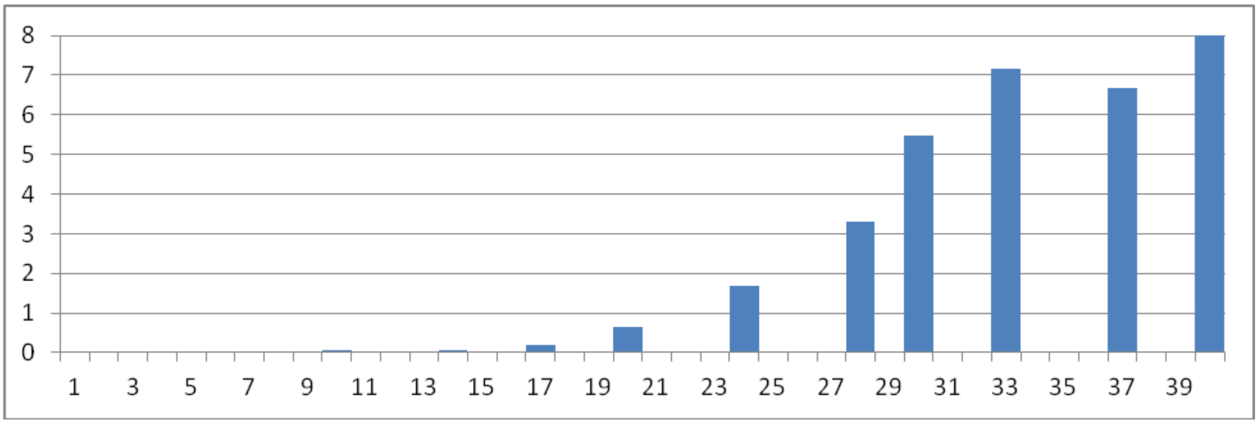
Mean number of adult moths per trap



Mean number of active mines per plant head



Mean number of Macrolophus per plant head

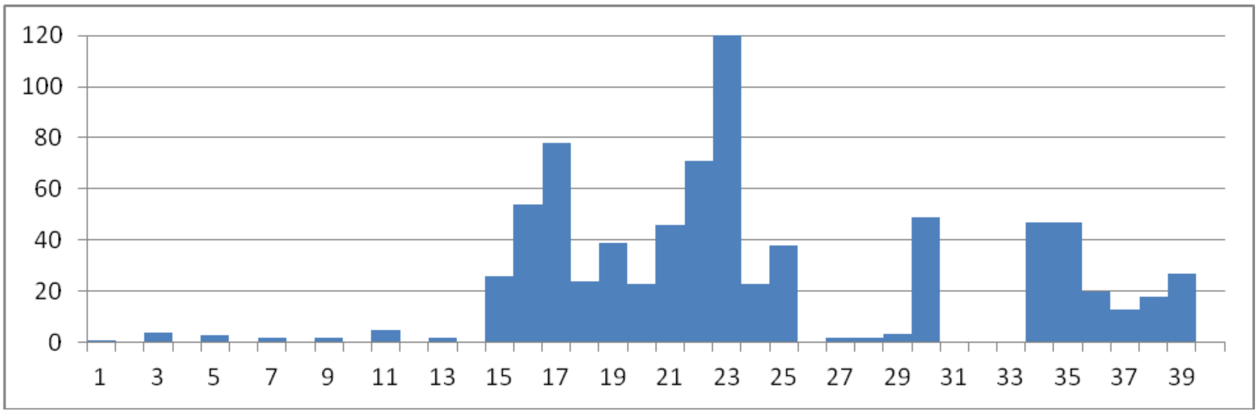


Week number

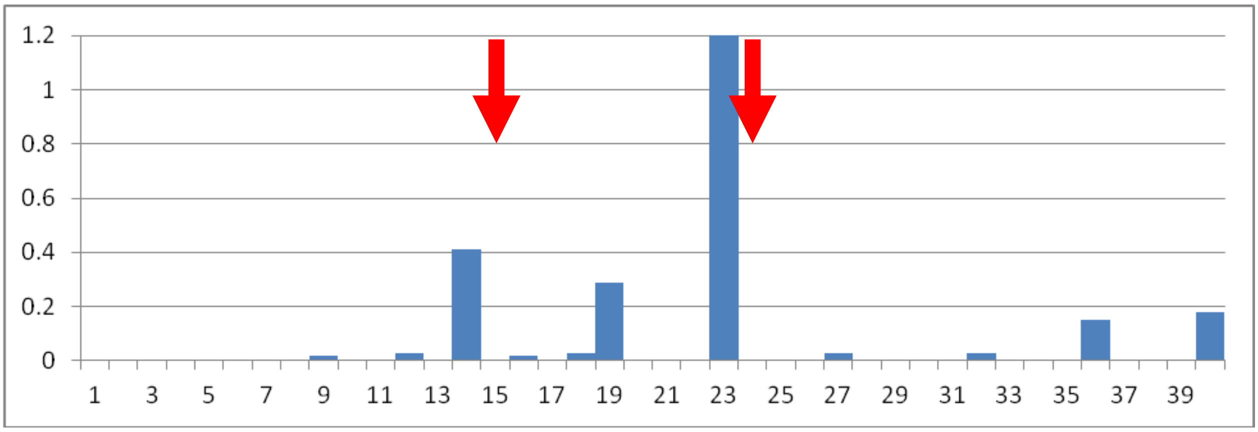
Product A via irrigation

Figure 1. Monitoring results from coir crop

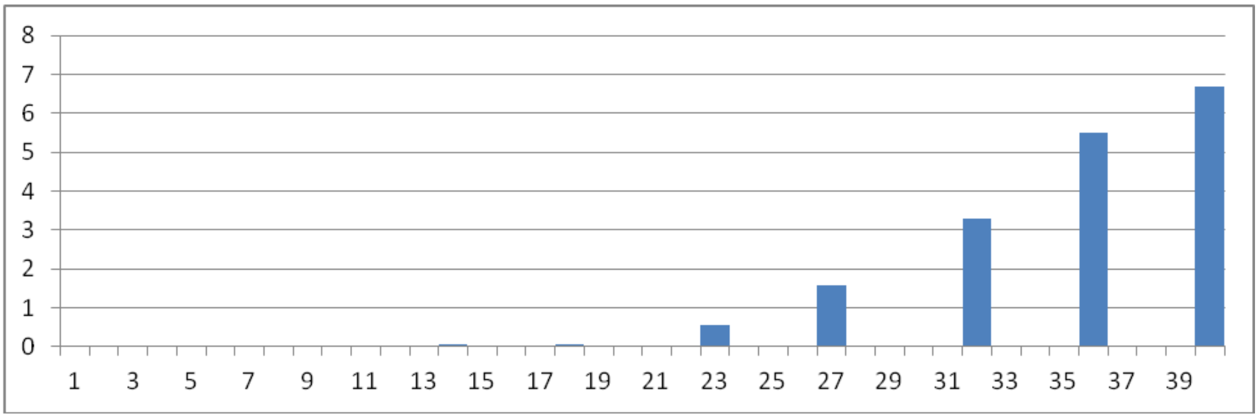
Mean number of adult moths per trap



Mean number of active mines per plant head



Mean number of Macrolophus per plant head



Week number

Product A via irrigation

Figure 2. Monitoring results from rockwool crop

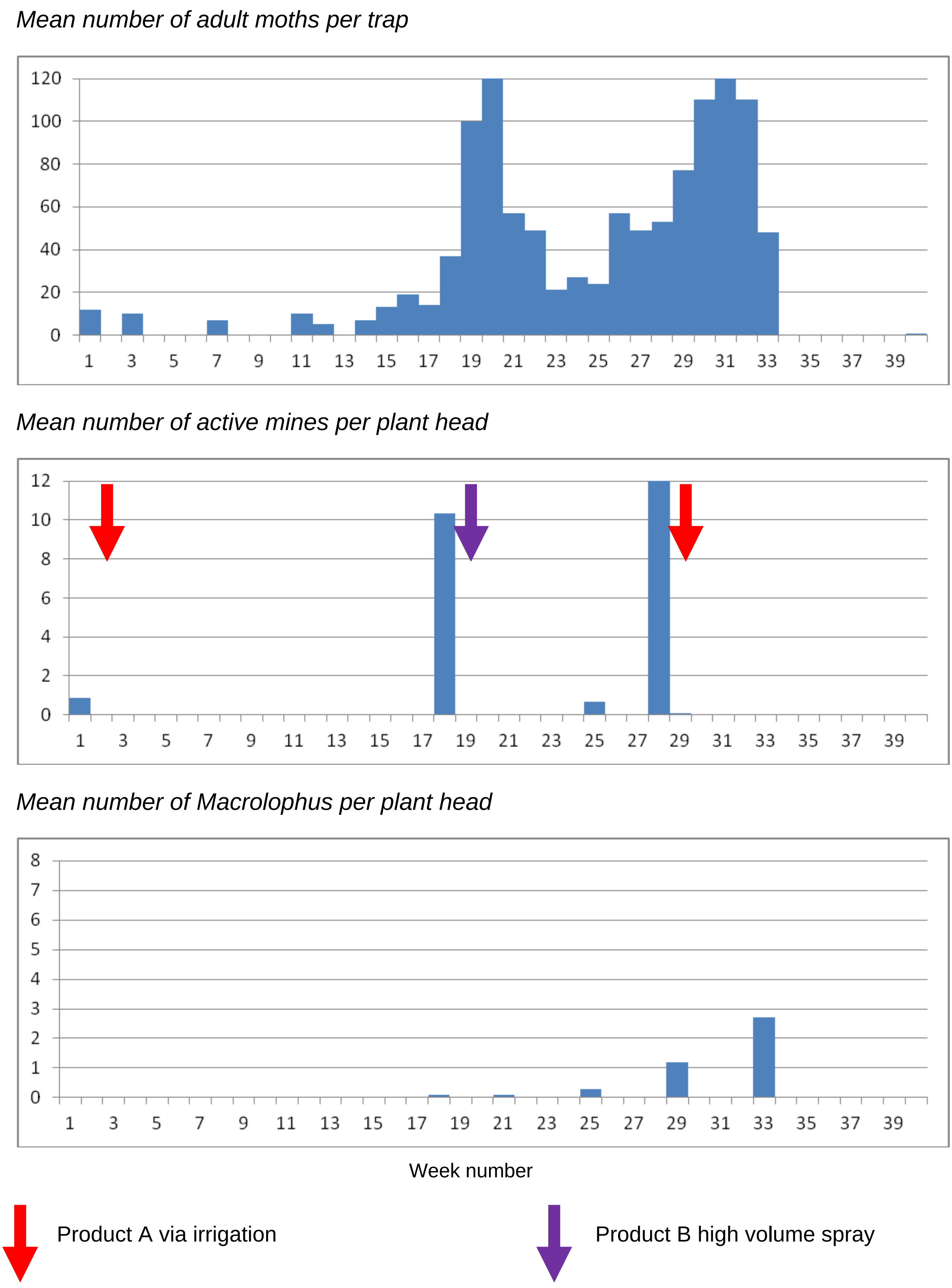
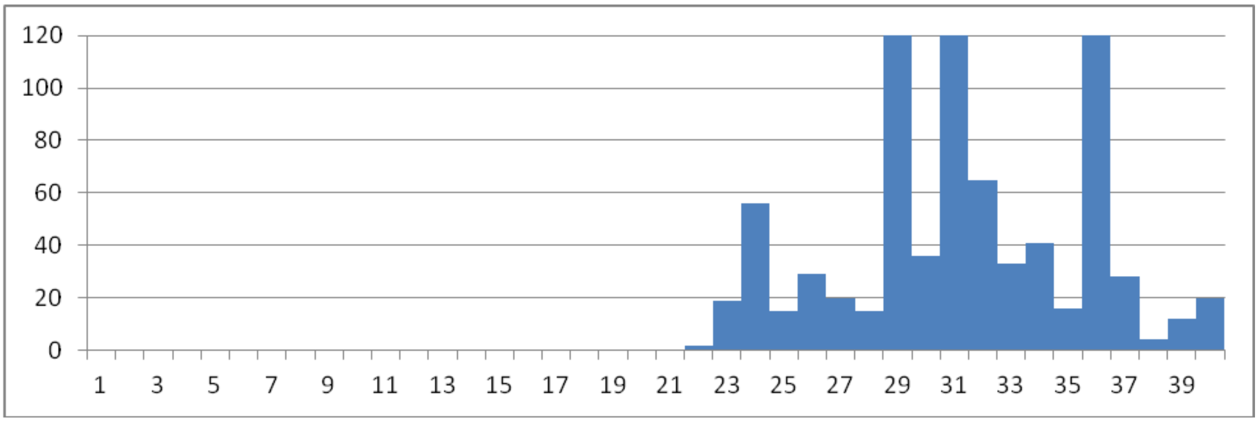
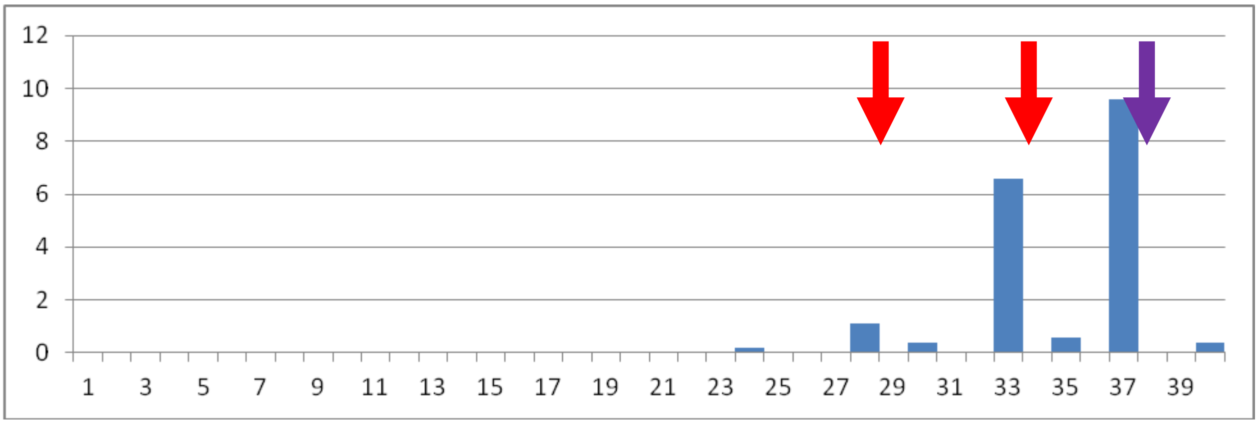


Figure 3. Monitoring results from NFT crop

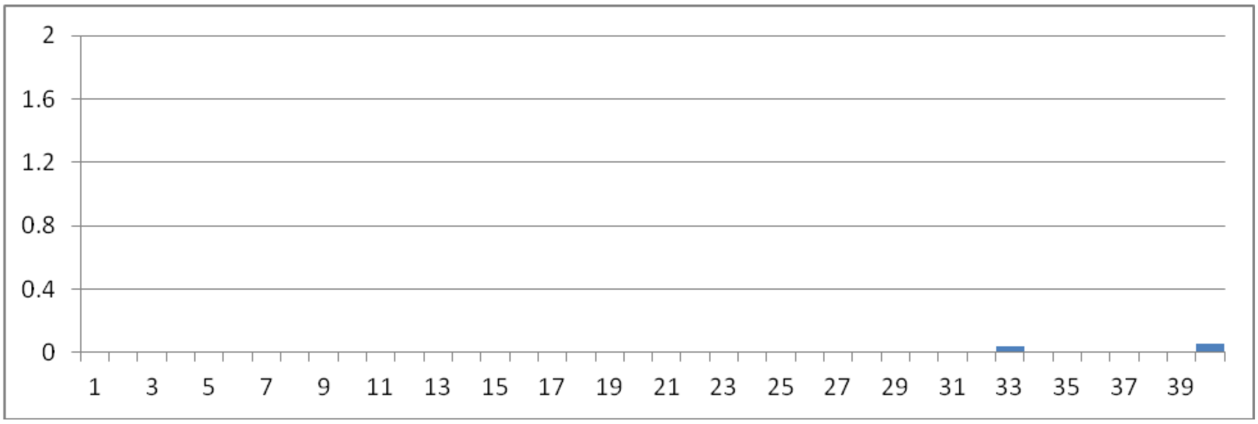
Mean number of adult moths per trap



Mean number of active mines per plan head



Mean number of Macrolophus per plant head



Week number

Product A via irrigation

Product B high volume spray

Figure 4. Monitoring results from soil crop

Conclusions

A new strategy for the control of *T. absoluta* within the existing tomato IPM programme was successfully evaluated in coir- and rockwool-grown tomato crops during the 2013 growing season. The same strategy was successful in a NFT-grown crop but a different approach to the release of the primary biocontrol agent led to delayed control and one additional application of insecticide. The whole IPM strategy has not yet been evaluated in soil-grown crops but the individual components are independently effective and should be equally successful when used in combination in organic tomato crops. We suggest growers take the following approach to controlling *T. absoluta*:

- It is important to have accurate topical information upon which to base decisions throughout the season. Counting active *T. absoluta* mines on the plants provides more reliable information than the use of pheromone traps. The counting procedure should be tailored to each individual site taking into account the type of crop, size of glasshouse and any other monitoring systems that are already in place. Counting *Macrolophus* should follow the guidelines provided in HDC Factsheet 14/10.
- *Macrolophus pygmaeus* should be released at the rate of 1 per m^2 as soon as possible after the plants are brought into the production glasshouse. The provision of supplementary food as *Artemia* feeding stations may aid establishment but requires further investigation.
- *Tuta absoluta* should be allowed to colonise the crop and then Product A applied via the irrigation system before the first caterpillars complete their development. This must be done in conjunction with a Plant Health Order for the control of *T. absoluta* and follow the instructions detailed in the EAMU provided by the Plant Health Inspector. The spinosad treatment can be supplemented by physical control methods including deleafing, sticky floor treatments and mass trapping with pheromone and / or light traps. However, it is difficult to quantify the real contribution made by such actions.
- Despite the measures taken to delay *T. absoluta* population growth up to this point, it seems inevitable that at least one SLoD treatment will be required before the predatory bugs start to have a significant impact. It is proposed that Product B be the first choice because it is completely compatible with *M. pygmaeus* and introduces different chemistry thus reducing resistance selection pressure. Product B high volume sprays must be done in conjunction with a Plant Health Order for the control of *T. absoluta* and follow the instructions detailed in the EAMU provided by the Plant Health Inspector. In some circumstances, treatment with Product A may have to be repeated.

- Other options for SLoD treatments include entomopathogentic nematodes and *Bacillus thuringiensis*, depending on the type of damage and type of crop. However, this must first be discussed and agreed with Plant Health section of FERA.
- By late-spring, *M. pygmaeus* should be more numerous and start to suppress the *T. absoluta* population growth by feeding on eggs and larvae. However, careful monitoring is required to determine whether it becomes necessary to apply additional SLoD treatments.
- If monitoring indicates that an end of season 'clean-up' treatment is required, then it is suggested that Steward® (indoxacarb) be used as it brings different chemistry to the programme and thus contributes to resistance management.

Knowledge and Technology Transfer

- Presentation to TGA Technical Committee, 3 June 2009
- Presentation to Tomato Conference 2009 (24 September 2009, Coventry); ‘Two more threats: *Tuta absoluta* and *Nesidiocoris tenuis*’.
- Article in HDC News (May 2009, 15); ‘A step ahead of the moth from the south’.
- Presentation to Tomato Pest and Disease Seminar (14 January 2010, Stoneleigh); ‘*Tuta absoluta*: Biology and control’.
- HDC Factsheet (January 2010, 03/10); ‘Tomato leafminers’.
- Article in HDC News (March 2010, 14); ‘Keep your guard up against exotic threats’.
- Article in HDC News (May 2010, Vol 163, 18-19); ‘Research catching up with *Tuta*’.
- PC 302 Project Update to TGA Technical Committee, 2 June 2010
- Invited presentation to Tomato Conference 2010 (September 2010, Coventry); ‘Update on *Tuta absoluta* and *Nesidiocoris tenuis*’.
- Article in Horticulture Week (15 October 2010, page 29). ‘Study says parasites key to Tuta control’.
- Article in HDC News (November 2010, Vol 168, 26-27); ‘*Tuta* meets its match’.
- Invited presentation to Tomato Conference 2011 (29 September 2011, Coventry); ‘*Tuta absoluta*: A realistic IPM approach’.
- Jacobson, R.J. & Martin, G. (2011). A potential role for entomopathogenic nematodes within IPM of Tuta absoluta (Meyrick) on organic tomato crops. *IOBC/WPRS Bulletin*, 68 (1), 71-74.
- Jacobson, R.J. (2011). *Tuta absoluta*: A season-long IPM strategy based on predatory bugs. *EPPO/IOBC/FAO/NEPPO International Symposium on management of Tuta absoluta (tomato borer).* Agadir, Morocco, 16-18 November 2011. 33-34
- Article in HDC News (September 2011, Vol 176, 26-27); ‘Fortified defences against tomato moth’.
- Article in Horticulture Week (14 October 2011, page 30). *Tuta absoluta* options move closer.
- Martin, G. & Jacobson, R.J. (2011). IPM of Tuta absoluta; A potential role for entomopathogenic nematodes in tomato production. “*Advances in Biocontrol*”. Grantham. 30 November 2011. P25
- Presentation to TGA Technical Committee, 15 February 2012
- Article in *TGA Newsletter* (July 2012. 5-7). *Tuta absoluta*: A season-long IPM strategy based on predatory bugs.
- Article in *TGA Newsletter* (August 2012. 5-7). More weapons in the armoury against

Tuta absoluta

- Presentation to TGA Technical Committee, 5 September 2012
- Invited presentation to Tomato Conference 2012 (27 September 20121, Coventry); *Tuta absoluta*: Another piece in the IPM jigsaw.
- Presentations to spray operators on NRoSo courses in Kent (9 October 2012), Evesham (23 October 2012), Chichester (24 October 2012), Isle of Wight (14 February 2013) and Norfolk (26 February 2013). 'Introduction to the biology and control of the new tomato pest – *Tuta absoluta*: Progress towards an IPM programme'.
- Invited presentation to Tomato Pest & Disease Workshop – Current issues and emerging threats. (17 January 2013). '*Tuta absoluta*'.
- Presentation to TGA Technical Committee, 14 March 2013
- Update to TGA Technical Committee, 4 December 2013

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Jacobson, R.J. and Morley, P (2006). Organic tomato: Development and implementation of a robust pesticide-free IPM programme. Horticultural Development Company Annual report for project PC 240, December 2006, 70pp

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