Project title:	Macrolophus as a biocontrol agent: Optimising release and feeding strategies
Project number:	PE 020
Project leader:	Mr Paul Howlett, Vitacress Chichester Food Park, Bognor Road, Chichester, West Sussex, PO20 1NW
Report:	Final report, November 2014
Previous report:	None
Key staff:	Dr J Fenlon, Warwick University Dr R Jacobson, RJC Ltd Ms V Kiss, Vitacress Mr B Moralee, Vitacress
Location of project:	Vitacress, Arreton, Isle of Wight RJC Ltd, Bramham, West Yorks Library at Fera Libraries at Lancaster, Leeds and York Universities Warwick University
Industry Representative:	Dr P Morley, (TGA Technical Officer) TGA, Pollards Nursery, Lake Lane, Barnham, West Sussex, PO22 3AR
Date project commenced:	01 January 2014
Date project completed (or expected completion date):	31 December 2014

DISCLAIMER

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 14/11/14

Report authorised by:

Mr P Howlett
Head of Agronomy
Vitacress Tomatoes

Signature .... Date 13-11-14

CONTENTS

GROWER SUMMARY

Headline

Provision of supplementary food can improve establishment of *Macrolophus pygmaeus* in tomato crops but further fine tuning is required to determine how that food should be presented to the predators.

Background

In 2013, HDC-funded project PC 302d developed a *Macrolophus*-based IPM strategy for the control of *Tuta absoluta.* Where the predator established well, the programme was highly successful but delays elsewhere resulted in additional interventions with chemical pesticides. *Macrolophus pygmaeus* population growth appeared to be improved when the predator was provided with supplementary food in the form of *Artemia* (brine shrimp) eggs. However, further investigation of the optimum rates of release and the true benefits of providing supplementary food were beyond the scope of that project. The Tomato Growers' Association Technical Committee requested that the project team continue studies on this subject starting from the beginning of the 2014 growing season.

Summary

The overall aim of the project was to improve the reliability of *Macrolophus pygmaeus* as a biocontrol agent on UK tomato crops. Specific technical objectives were to:

- To evaluate a range of release rates and approaches to the provision of supplementary food.
- Draft a Factsheet for UK growers describing in detail the new strategy.
- Convey results to tomato industry.

The approach

This project was designed to evaluate the speed of *M. pygmaeus* population growth from six combinations of release rate and feeding strategies on two types of cultivars. The trials work was done in commercial tomato crops following the general approach that was successfully developed in HDC project PC 240 and more recently used in HDC projects PC 251, PC 295 and PC 302/b/d. This approach has immediately identified any important interactions with current agronomic practice and thereby eliminated the need for an additional exploitation phase to transfer the technology to the commercial situation. In all examples provided above, the results of the research were implemented by growers within the duration of the projects.

The main trial utilised four identical glasshouses with each divided into two halves by a central roadway. The basic treatment comprised an application of one *M. pygmaeus* / m^2, released on tomato cv Mecano (a classic round tomato type) three weeks after the plants arrived and fed with *Artemia* cysts at four week intervals. There was a sub-division of this treatment with *Artemia* cysts either applied at distinct feeding stations or broadcast more generally from a Koppert dispenser. There were three variations of the basic treatment:

1. with the *M. pygmaeus* release rate halved
2. the *M. pygmaeus* release made earlier
3. the cultivar changed to cv Angelle (a baby plum tomato type)

In each case, the sub-divisions with *Artemia* eggs applied at feeding stations or broadcast was retained.

Additional treatments were introduced in three similar sized crops of cv Angelle. In all cases, *M. pygmaeus* was released at the rate of 1 / m^2 three weeks after the plants arrived. One crop received no supplementary food while the other two received more frequent applications of decapsulated *Artemia* eggs either at feeding stations or broadcast.

The findings

The main outcome from this trial was that *M. pygmaeus* population growth was markedly greater on cv Angelle than on cv Mecano with 40% more predators on cv Angelle at the end of the trial. This was broadly consistent with results from previous projects which have explored the susceptibility of speciality tomato cultivars to a range of insect pests. At some stage, it may become important to fine tune IPM programmes by categorising the performance of pests and beneficial insects on each type of tomato currently grown. However, in the short term there are other factors to address which could have greater immediate impact across all tomato types.

The results from this project reinforced the observations from PC 302d which indicated that *M. pygmaeus* population growth was greater when the predators were provided with supplementary food. However, we were unable to demonstrate any significant difference between the six combinations of *M. pygmaeus* release rate and feeding strategies, and were therefore unable to further refine the use of this predator.

Subjective in-crop observations indicated that there was a high level of natural mortality of *M. pygmaeus* immediately after release in the crop. This was based on the presence of large numbers of dead *M. pygmaeus* on plants within 48 hours of release. The observations were supported by survival tests done in the laboratory. The actual percentage mortality could not be quantified in the crop because it was impossible to track all the predators after release. However, the concern was such that independent laboratory-based studies were instigated to investigate the issue. The results of these studies are beyond the scope of this report but they indicate that the impact of the natural mortality could have masked smaller differences between *M. pygmaeus* release rate and feeding strategies within this project.

In parallel to the main trial, the team undertook a more in depth study of *Artemia*-based food materials. *Artemia* are collected in bulk from the surface of salt lakes in various parts of the world. They are usually in an encysted form which is able to resist extreme adverse conditions for long periods of time. They are used by the fish farming industry either in the collected form or in a 'decapsulated' state which has the outer coating removed by an industrial process. The quality of the material apparently varies according to the geographical origin and the extent of the industrial processing.

Upon delivery, the *Artemia* material is dehydrated but rapidly rehydrates if placed upon a damp pad. Our experience indicates that there is insufficient moisture in the crop canopy to hydrate the material and retain it in that state. Given that *M. pygmaeus* have 'piercing and sucking', rather than 'chewing', mouthparts we believe that this is a serious impediment to successful feeding.

In the light of knowledge gained this growing season, we believe that *M. pygmaeus* population growth could be significantly improved by hydrating the *Artemia*-based food during use. This will require a completely new and novel feeder system which will keep the *Artemia* in a suitable state of hydration for sufficient time to influence *M. pygmaeus* feeding and population growth.

Financial Benefits

- *Macrolophus pygmaeus* is potentially one of the most useful biological control agents available to tomato growers but, at £70 - £80 / 1,000, it also one of the most expensive. Hence, it must be used to best effect. A saving in release of only 0.25 *M. pygmaeus* / m^2 across 66% of the UK tomato industry would equate to a saving of over £24k thus giving immediate payback on this project in one season.
- *Liriomyza* leafminers are currently the most expensive pests to control with biological control agents in tomato crops. Improved use of *M. pygmaeus* could provide savings of £400-£800 per hectare for growers who suffer this problem.
- *Tuta absoluta* is one of the most important pests of tomato crops in the UK. For example, at one nursery in 2012, 30% of fruit were damaged by the pest and graded out during June and July. This represented losses of approx £50k per hectare to that grower for that period alone. Where successful, the *Macrolophus*-based control strategy has prevented such damage. Hence, avoiding the situation described in this example alone would provide an immediate x2 payback on the cost of this project.

Action Points

- The provision of supplementary food can enhance population growth of *M. pygmaeus* in commercial crops.
- *Macolophus pygmaeus* population growth varies significantly between tomato cultivars. In the present case, there were 40% more predators on tomato cv Angelle than on cv Mecano at the end of the trial.
- *Macolophus pygmaeus* are vulnerable to stresses associated with short-term storage, packaging and transport which we believe led to high levels of natural mortality of the material supplied to this trial. Growers must take this into account when receiving and handling deliveries of *M. pygmaeus*.
- Parallel studies have shed more light on the importance of the type of supplementary food provided to *M. pygmaeus*. In particular, it seems that the state of hydration of *Artemia* cysts / eggs could be critical to their value as a food material. This requires further investigation and potentially the development of a feeding unit that maintains the supplementary food in an optimal state for the predators.

SCIENCE SECTION

Introduction

Background

Macrolophus adults and nymphs are voracious predators. They were first released in the UK under licence as *M. caliginosus* in 1995 to supplement the biological control of glasshouse whitefly. Within two growing seasons it became clear that the predators would also feed on the tomato plants when invertebrate prey was limiting (Hayman & Jacobson, 1996). The damage to growing points and trusses could be extremely serious with losses in some organic crops estimated to exceed £72k/ha per season (Starkey, unpublished data, 2004). Although UK growers stopped releasing '*M. caliginosus'*, the insects survived between seasons and it became one of the most important pests of organic tomatoes in the UK. An HDC-funded project (PC 240) in 2006 developed a means of managing *Macrolophus* populations which allowed UK growers to obtain their predatory benefits without suffering crop damage (Jacobson & Morley, 2006). This resulted in renewed interest in the predator and growers started to release it again to aid the control of whiteflies, *Liriomyza* leaf miner, spider mites and, most recently, *Tuta absoluta.* At best, the predator provides excellent control of all these pests. However, results have been inconsistent and it is important to improve the robustness of this potentially valuable component of the IPM programme.

Anomalies relating to the taxonomy of the *Macrolophus* complex of species have caused confusion since the predator was first released in UK tomato crops in the mid-1900s. Studies at a molecular level in a previous project (PC 302c) showed that the species previously reported to be *M. caliginosus* (= *M. melanotoma*) was actually *M. pygmaeus* (Hodgetts & Ostoja-Starzewski, 2012). However, this revelation was simply related to nomenclature and has probably not affected the consistency of *Macrolophus* spp. performance in IPM programmes during the intervening period.

In 2013, HDC-funded project PC 302d developed a *Macrolophus*-based IPM strategy for the control of *Tuta absoluta.* Where the predator established well, the programme was highly successful but delays elsewhere resulted in additional interventions with chemical pesticides. *Macrolophus pygmaeus* population growth appeared to be improved when the predator was provided with supplementary food in the form of *Artemia* (brine shrimp) and / or *Ephestia* spp. (a stored product moth) eggs. However, further investigation of the optimum rates of release and the true benefits of providing supplementary food were beyond the scope of that project (Jacobson & Howlett, 2013). The Tomato Growers' Association Technical Committee requested that the project team continue studies on this subject starting from the beginning of the 2014 growing season (Minutes of TGA TC meeting on 4 December 2013).

To summarise, the present project was designed to evaluate the speed of *M. pygmaeus* population growth from six combinations of release rate and feeding strategies on two types of cultivars. The trials work was planned for commercial nurseries following the general approach that was successfully developed in HDC project PC 240 (Jacobson & Morley, 2009) and more recently used in HDC projects PC 251 (Jacobson, 2008), PC 295 (Jacobson, 2009) and PC 302/b/d (Jacobson & Morley, 2010; Jacobson & Howlett, 2012; Jacobson & Howlett, 2013). This approach immediately identified any important interactions with current agronomic practice and thereby eliminated the need for an additional exploitation phase to transfer the technology to the commercial situation. In all examples provided above, the results of the research were implemented by growers within the duration of the projects.

Objectives of project PC 302d

The overall aim of the project was to improve the reliability and consistency of *Macrolophus pygmaeus* as a biocontrol agent on UK tomato crops. Specific technical objectives were to:

- To evaluate a range of release rates and approaches to the provision of supplementary food.
- Draft a Factsheet for UK growers describing in detail the new strategy.
- Convey results to tomato industry.

Materials and methods

The main trial was done in four similar 3,400m^2 glasshouses at Lane End Nursery, Arreton, Isle of Wight. Each glasshouse was divided into two by a central roadway thereby providing a total of eight large plots. These glasshouses housed the eight main treatments. In addition, three supplementary treatments were evaluated in comparable sized glasshouses at Macketts Land Nursery, Arreton, Isle of Wight. The details of the eleven treatments are shown in Table 1.

Three of the glasshouses at Lane End Nursery contained tomato cv Mecano and the fourth contained tomato cv Angelle. All these plants arrived from the plant propagators on 31 December 2013 (week 1, 2014). The supplementary treatments at Macketts Land Nursery were done on tomato cv Angelle with plants arriving on 3 January 2014 (week 1, 2014).

Macrolophus pygmaeus was provided by BCP Certis at Lane End Nursery and by Syngenta Bioline at Macketts Land Nursery. The 'earlier-release' treatment (glasshouse C) was applied upon delivery to the plants while they were still in the delivery crates. *Macrolophus pygmaeus* were supplied as mixed life cycle stages which were sprinkled as evenly as possible over the plants. Elsewhere, *M. pygmaeus* releases were made three weeks after the plants arrived (*i.e.* in week 4, 2014). Both the feeding station and broadcast treatments made use of 'bug boxes' with the equivalent of 200 boxes per hectare (Figure 1). *Macrolophus pygmaeus* were placed in these boxes with distribution as even as possible across the glasshouses.

The supplementary food was supplied by Certis BCP at Lane End Nursery and by Syngenta Bioline at Macketts Land Nursery. The *Artemia* from Certis BCP was in the form of cysts while Syngenta Bioline supplied as de-capsulated eggs.

Glasshouse C (early release treatment) received the first application of supplementary food while the plants were still in the delivery crates (*i.e.* immediately after application of *M. pygmaeus*). The rate was equivalent to 250g food per ha of final plant spacing and the material was sprinkled over the plants as evenly as possible. The second application was made at the same rate in week 4 2014 following procedures described below for both the feeding station and broadcast treatments. Thereafter, applications were made at four week intervals (Table 2) until general pest monitoring (see below) showed this to be no longer necessary. The decision to stop feeding was based on the availability of food in the form of other pests and was made following discussion between the growers, biocontrol suppliers and Dr Jacobson.

The feeding station treatments at Lane End Nursery received supplementary food at the equivalent of 250g food per ha in week 4 and at 4 week intervals thereafter (Table 2). The material was concentrated on 32 plants in the immediate area of each bugbox (Figure 2). The broadcast treatments were applied using the Koppert applicator (Figure 2) with the food being applied more generally throughout the crop, at the equivalent of 250g per ha, in week 4 and at 4 week intervals thereafter (Table 2). In all cases, application of supplementary food continued until pest monitoring assessments showed this to be no longer necessary.

The dates and methods of supplementary food application were similar at Macketts Land Nursery until week 8. Thereafter, the food was applied at weekly intervals, which was in line with the feeding strategy recommended by the supplier of the de-capsulated eggs. Supplementary feeding stopped after week 16.

Table 1. Details of all treatments at Lane End Nursery and Macketts Land Nursery

Site	**Glasshouse**		**Cultivar**	**Macrolophus**	**Artemia**	**Feeding method**
	Reference number	**Area (m^2)**				
Lane End	A1	1700	Mecano	1/m^2	Feed station	-
	A2	1700	Mecano	1/m^2	Broadcast	-
	B1	1700	Mecano	0.5/m^2	Feed station	-
	B2	1700	Mecano	0.5/m^2	Broadcast	-
	C1	1700	Mecano	1/m^2 at delivery	Feed station	-
	C2	1700	Mecano	1/m^2 at delivery	Broadcast	-
	D1	1700	Angelle	1/m^2	Feed station	-
	D2	1700	Angelle	1/m^2	Broadcast	-
Macketts Land	E	1501	Angelle	1/m^2	-	None
	F1	1501	Angelle	1/m^2	-	Broadcast
	F2	1501	Angelle	1/m^2	-	Feed station

Table 2. Dates of release of *Macrolophus pygmaeus* and provision of supplementary food in the eleven treatments

Glasshouse reference	Week number				
	Macrolophus in	**First feed**	**Second feed**	**Third feed**	**Thereafter**
A1	4	4	8	12	-
A2	4	4	8	12	-
B1	4	4	8	12	-
B2	4	4	8	12	-
C1	1	1	4	8	12
C3	1	1	4	8	12
D1	4	4	8	12	-
D4	4	4	8	12	-
E	4	4	8	12	-
F1	4	4	8	Then weekly until week 16	
F2	4	4	8	Then weekly until week 16	

Figure 1. Bug boxes as supplied by Certis BCP (left) and Syngenta Bioline (right).

Figure 2. Supplementary feed on a leaf in the immediate area of a bug box in the ‘feeding station’ treatments (left) and the Koppert applicator used to spread the food more generally throughout the crop canopy in the ‘broadcast’ treatments.

Numbers of *M. pygmaeus* were recorded at three week intervals using the technique developed in HDC Project PC240 (Jacobson & Morley, 2009). Where glasshouses were divided into two treatments, there was a buffer zone of 12m at each side of the central road which was not included in the assessments. Five pathways out of a total of 17 within each treatment area were selected as ‘sub-plots’ for the purpose of statistical analysis. Within each sub-plot there were ten evenly distributed sample stations, with each consisting of 3 plant heads. The top of the plant (including two expanded leaves) was tapped four times over a white tray and the number of *M. pygmaeus* (adults and nymphs) per sample station recorded.

The trial was conducted in the knowledge that there was no formal replication. In this situation, a surrogate error is usually derived from the sampling structure within each glasshouse (*i.e.* four sub-plots sampled in each house with 10 sample points from each) with the major tool of analysis being analysis of variance. The sampling variation within each treatment area was combined and used as a test for differences between means of the samples from each plot. In practice, this method proved to be inappropriate because many of the data were zeros. Nevertheless, the distribution of the sampling variance between glasshouses, crop rows and sample points for the two sites were similar and consistent over time, so it was reasonable to examine the total numbers for the eleven glasshouses in a single analysis for each of the weekly readings. .

In the first instance, the data from the main trial plots at Lane End Nursery was formally examined by exploiting the factorial structure of the trial. For example, glasshouses A, B and C contained the cv Mecano, and glasshouse D was planted with cv Angelle so, in looking at the 3 degrees of freedom for comparisons between glasshouses a single d.f. contrast was extracted for comparison of the two cultivars. Similarly, comparisons were made between release rate of *M. pygmaeus* (*i.e.* glasshouses A vs. B and C) and between timing of release of *M. pygmaeus* (*i.e.* glasshouses A and B vs. C). The additional treatments at Mackett's Land Nursery allowed a direct comparison between unfed and fed *M. pygmaeus* (*i.e.* glasshouses E vs. F). In addition, they contained cv Angelle and so formed a link to glasshouse D allowing further comparisons (albeit less formal) between cultivars and presence of food.

In addition to the *M. pygmaeus* assessments, the growers provided a weekly subjective report on the general pest situation. Decisions regarding the choice and timing of control measures against other pests were made following discussion between the growers, biocontrol suppliers and Dr Jacobson.

Results and Discussion

Figure 3 shows a comparison of the broadcast feeding method (treatments A1, B1 and C1) with the feeding station method (A2, B2 and C2) within cv Mecano over the 21 weeks of the trial. There was a suggestion of difference on weeks 17 and 19, although they acted against each other in that the broadcast mean was higher than the feeding station mean at week 17 but this was reversed two weeks later. The differences were not significant. The same comparison is shown for cv Angelle in Figure 4 (D1 vs. D2). Once again, there was no significant difference. Therefore, the feeding method sub-divisions were linked together and considered as one in all the subsequent comparisons.

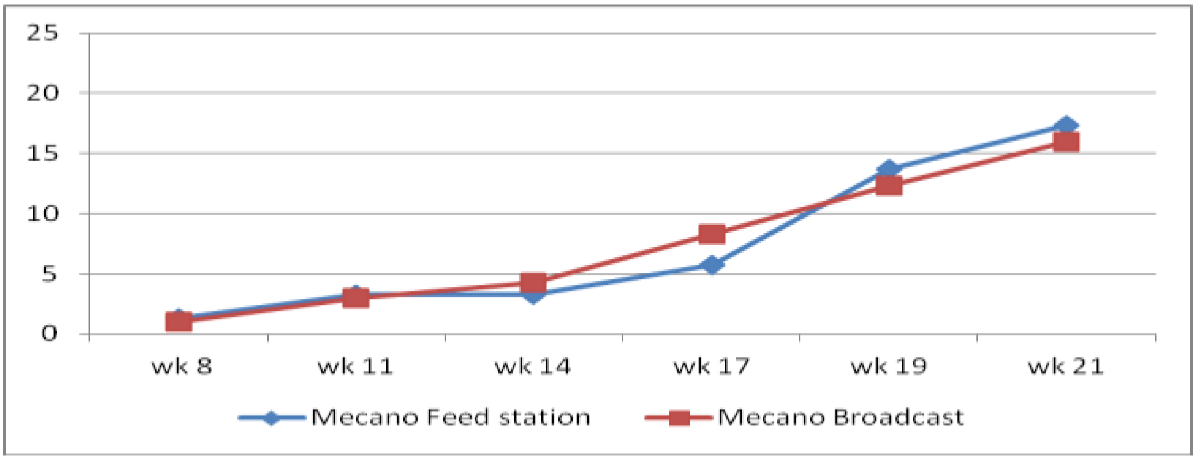

Figure 3: Mean total numbers of *Macrolophus pygmaeus* on sampled plants in the broadcast and feeding station treatments on cv Mecano over 21 weeks

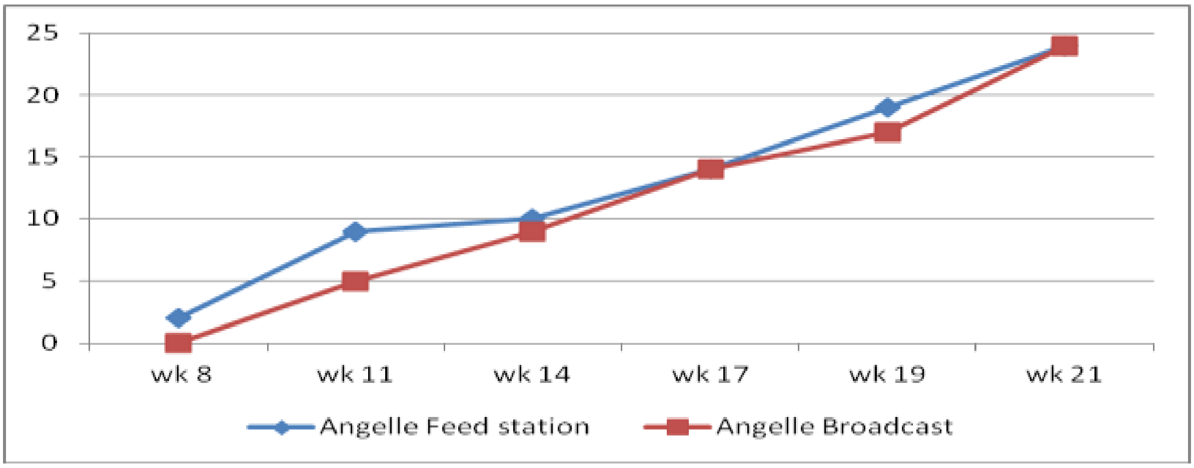

Figure 4: Mean total numbers of *Macrolophus pygmaeus* on sampled plants in the broadcast and feeding station treatments on cv Angelle over 21 weeks

Figure 5 shows the mean total numbers of *M. pygmaeus* on the two cultivars over 21 weeks in the main trial at Lane End Nursery. The differences were highly significant (*p<0.01*) from week 14 onwards with consistently more *M. pygmaeus* present on cv Angelle (glasshouse D) than on cv Mecano (glasshouses A, B and C). At week 21, there were approximately 40% more *M. pygmaeus* on cv Angelle than cv Mecano. Figure 6 also compares the mean total numbers of *M. pygmaeus* on the two cultivars but, in this case, incorporates data from the additional treatment in glasshouse F at Macketts Land Nursery. The result was comparable to above although the differences were only significant (*p<0.*05) at weeks 17 and 21 (*nb.* for weeks 14 and 19 the significant level was just missed [*0.05<p<0.*10]). This clearly reinforced the result from the main trial.

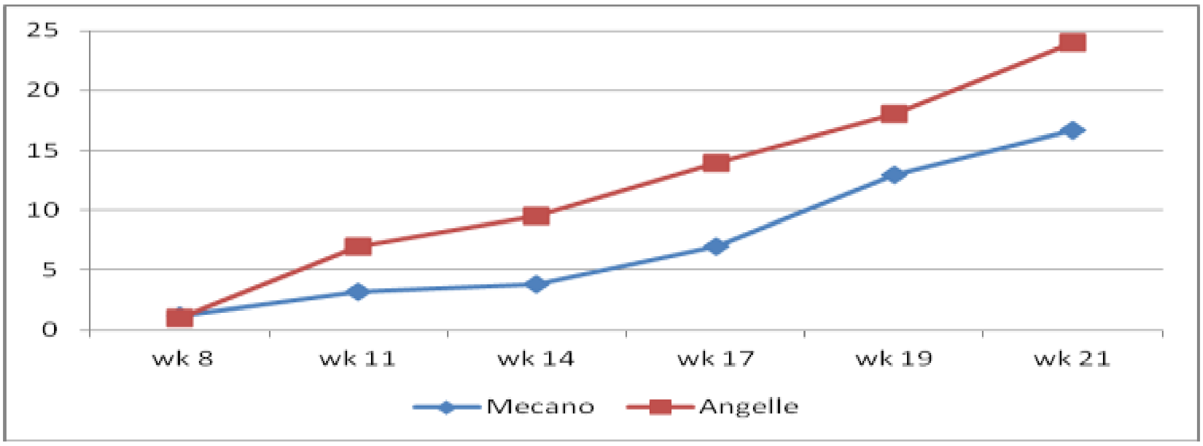

Figure 5. Mean total numbers of *Macrolophus pygmaeus* on cv Angelle and cv Mecano over 21 weeks in the main trial at Lane End Nursery.

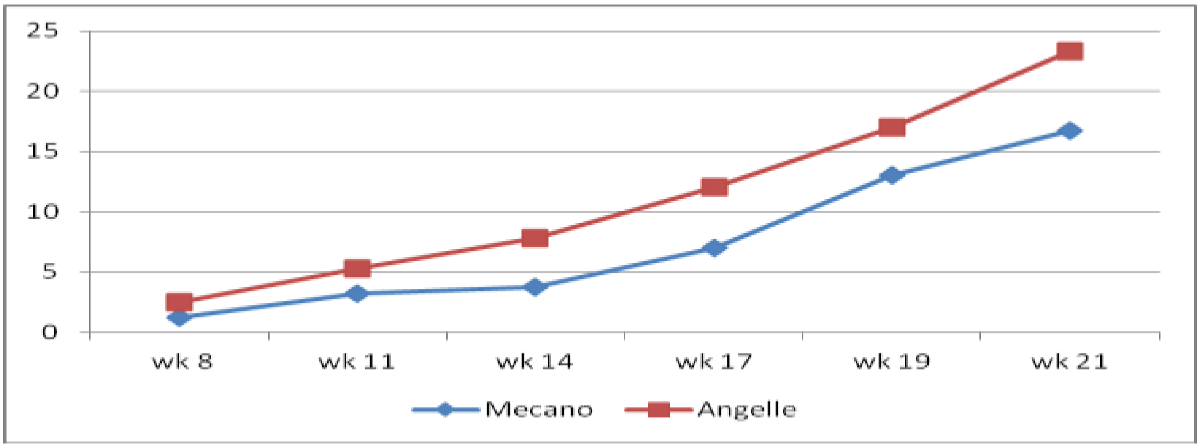

Figure 6. Mean total numbers of *Macrolophus pygmaeus* on cv Angelle and cv Mecano over 21 weeks in all crops which received supplementary feed at both Lane End Nursery and Macketts Land Nurserery.

Figure 7 shows the comparison between the higher and lower *M. pygmaeus* release rates on cv Mecano including all the treatments that incorporated the high rate (A1, A2, C1, C2) and all the treatments that incorporated the lower rate (B1, B2) There was no significant difference.

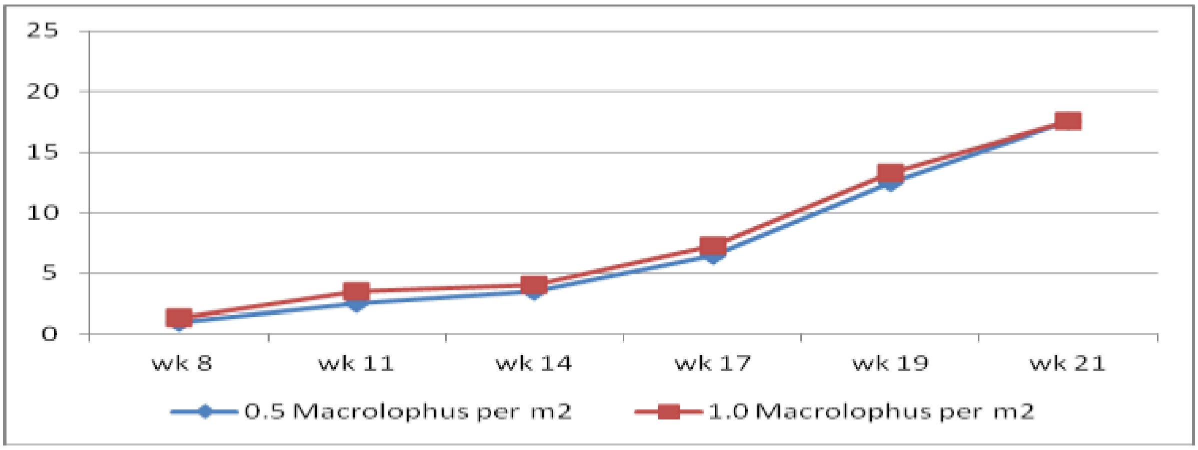

Figure 7. Numbers of *Macrolophus pygmaeus* over 21 weeks when applied at two release rates on cv Mecano

Figure 8 shows the comparison between the two release timings of *M. pygmaeus* on cv Mecano. All the treatments that incorporated the later timing are combined (A1, A2, B1, B2) as are all the treatments that incorporated the earlier release timing (C1, C2). Although there was no apparent difference at the latter end of the trial, numbers of *M. pygmaeus* did diverge slightly numbers at weeks 11 and 14 which could have been important if pests had been present in the crop at that time.

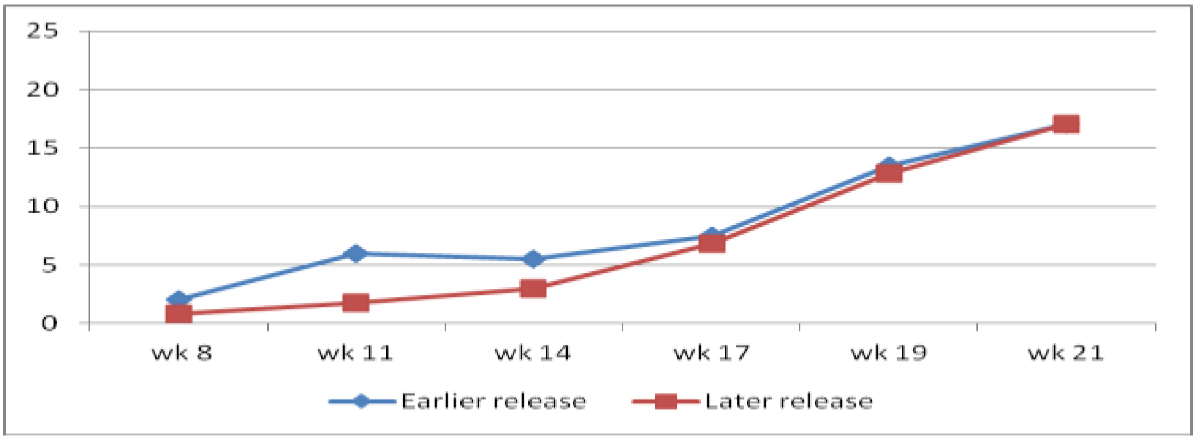

Figure 8. Numbers of *Macrolophus pygmaeus* over 21 weeks when applied at two release timings on cv Mecano.

The final comparison is between the treatments which received supplementary food and those which did not at Macketts Land Nursery (*i.e.* glasshouses E vs. F). These comparisons must be interpreted with more caution because the data and analysis were less robust. Nonetheless, the apparent difference was quite striking with approximately 40% more *M. pygmaeus* at week 21 when they had received supplementary food (Figure 8).

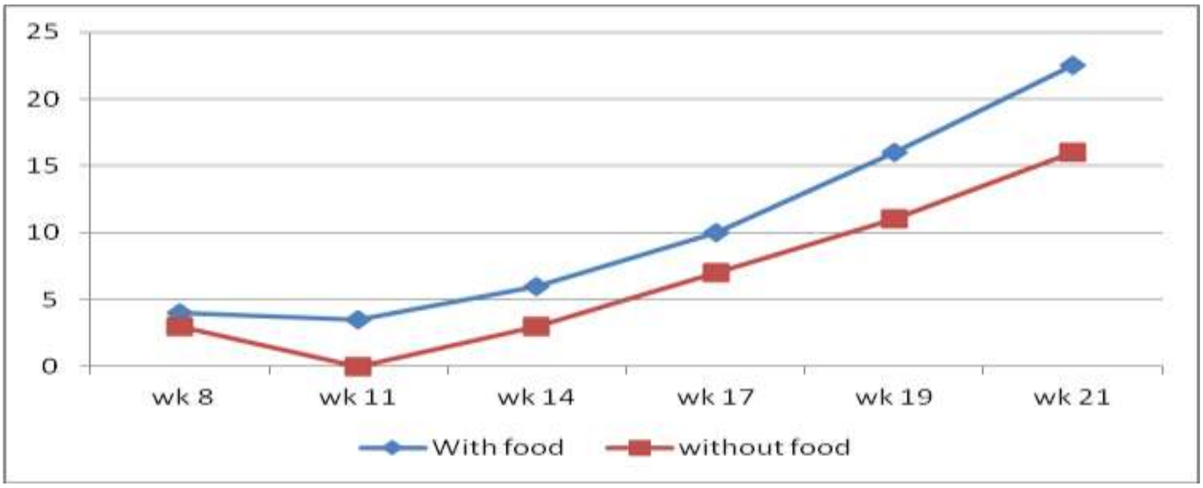

Figure 8. Numbers of *Macrolophus pygmaeus* on cv Angelle with and without supplementary food over 21 weeks at Macketts Land Nursery

The main outcome from this trial was that *M. pygmaeus* population growth was markedly greater on cv Angelle (a baby plum tomato type) than on cv Mecano (a classic round tomato type). This was consistent with previous projects which have explored the susceptibility of speciality tomato cultivars to a range of insect pests (Jacobson & Morley, 2006; Jacobson and Morley, 2008). At some stage, it may become important to fine tune IPM programmes by categorising the performance of pests and beneficial insects on each type of tomato. However, in the short term there are other factors to address which could have greater immediate impact across all tomato types.

The results from this project reinforced the observations from 2013 (Jacobson & Howlett, 2013) which indicated that *M. pygmaeus* population growth was greater when the predators were provided with supplementary food. However, we were unable to demonstrate any significant difference between the six combinations of *M. pygmaeus* release rate and feeding strategies, and were therefore unable to further refine the use of this predator.

Subjective in-crop observations indicated that there was a high level of natural mortality of *M. pygmaeus* immediately after release in the crop. This was based on the presence of large numbers of dead *M. pygmaeus* on plants within 48 hours of release. The observations were supported by survival tests in the laboratory (Jacobson, Unpublished data, 2014). The actual percentage mortality could not be quantified in-crop because it was impossible to track all the predators after release. However, the concern was such that independent laboratory-based studies were instigated to investigate the issue. The results of these studies are beyond the scope of this report (Jacobson, Unpublished data, 2014) but they indicate that the impact of the natural mortality could have masked smaller differences between *M. pygmaeus* release rate and feeding strategies explored within this project.

In parallel to this project, the team undertook a more in depth study of *Artemia*-based food materials. *Artemia* are collected in bulk from the surface of salt lakes in various parts of the world. They are usually in an encysted form (Figure 9) which is able to resist extreme adverse conditions for long periods of time. They are used by the fish farming industry either in the collected form or in a ‘decapsulated’ state (Figure 10) which has the outer coating removed by an industrial process. The quality of the material apparently varies according to the geographical origin and the extent of the industrial processing.

Upon delivery, the *Artemia* material is dehydrated but rapidly rehydrates if placed upon a damp pad (Figures 9 and 10). Our experience indicates that there is insufficient moisture in the crop canopy to hydrate the material and retain it in that state. Given that *M. pygmaeus* have ‘piercing and sucking’, rather than ‘chewing’, mouthparts we believe that this is a serious impediment to successful feeding.

In the light of knowledge gained this growing season, we believe that *M. pygmaeus* population growth could be significantly improved by hydrating the *Artemia*-based food prior to and during use. This will require a completely new and novel feeder system which will keep the *Artemia* in a suitable state of hydration for an acceptable time to influence *M. pygmaeus* feeding and population growth.

Figure 9. *Artemia* cysts as delivered in the dehydrated state (left) and following rehydration on a damp pad (right)

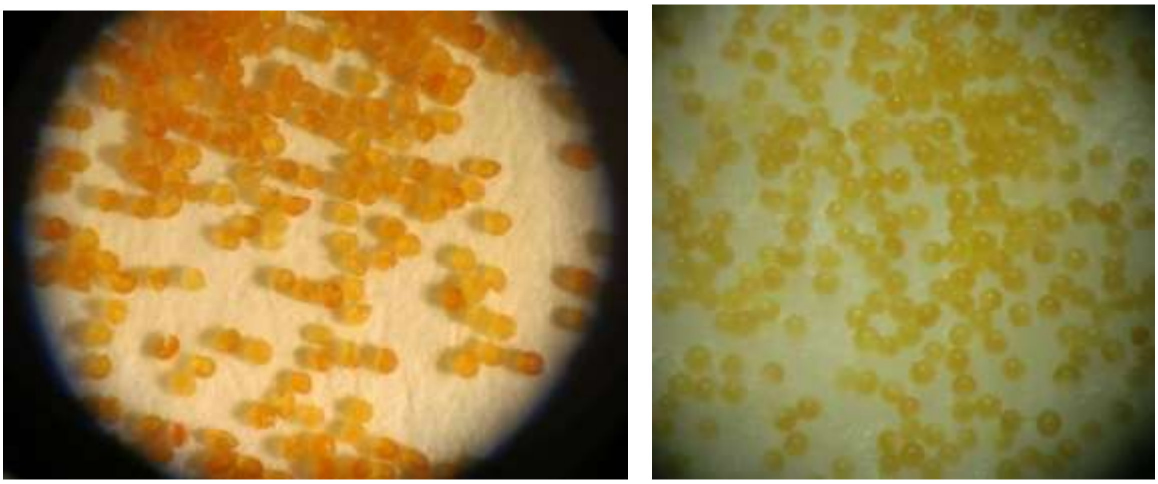

Figure 10. ‘Decapsulated’ *Artemia* cysts as delivered in the dehydrated state (left) and following rehydration on a damp pad (right)

Conclusions

Several conclusions can be drawn from the data produced by this project and the associated studies:

- The provision of supplementary food can enhance population growth of *M. pygmaeus* in commercial crops.
- *Macolophus pygmaeus* population growth varies significantly between tomato cultivars. In the present case, there were 40% more predators on tomato cv Angelle than on cv Mecano at the end of the trial. At some stage, it may become important to fine tune IPM programmes by categorising the performance of pests and beneficial insects on each type of tomato. However, in the short term there are other factors to address which could have more immediate impact across all tomato types
- *Macrolophus pygmaeus* appeared to be extremely vulnerable to stresses associated with short-term storage, packaging and transport which we believe led to high levels of natural mortality of the material supplied to this trial. This is not a unique observation. The fragility of this type of soft-bodied beneficial insect has been previously reported (Jacobson, 2011).
- The project did not identify any differences in the rates or timing of release of *M. pygmaeus*. Nor were there differences in the method of application of supplementary food. However, we believe that such differences could have been masked by the greater impact of natural mortality of the supplied *M. pygmaeus*.
- Parallel studies have shed more light on the importance of the type of supplementary food provided to *M. pygmaeus*. In particular, it seems that the state of hydration of the *Artemia* cysts / eggs could be critical to their value as a food material (Jacobson, Unpublished data, 2014).
- The combined studies have moved our knowledge another step forward and thereby paved the way for the next stage of the investigation. It is recommended that the following issues be addressed:
    - Levels of natural mortality of delivered *M. pygmaeus*.
    - Comparative value of *Artemia* cysts and decapsulated eggs as food sources to *M. pygmaeus*.
    - The importance of the state of hydration of supplementary food to its value to *M. pygmaeus*.
    - The need for the development of a feeding unit that maintains supplementary food in an optimal state for *M. pygmaeus*.

Knowledge and Technology Transfer

- Update to TGA Technical Committee, 4June 2014
- Update to TGA Technical Committee, 3 September 2014
- Article for December 2014 issue of HDC News – In press

References

Hayman, G. and Jacobson, R. J. (1996). Not so beneficial insects? *Grower*, 126 (9), 13.

Hodgetts, J. and Ostoja-Starzewski, J. (2012). Optimising the *Macrolophus*-based *Tuta absoluta* IPM strategy: Phase 1 – Identification of species on UK nurseries. Horticultural Development Company Final report for project PC 302c, March 2013, 23pp

Jacobson, R.J. (2008). AYR tomato production: Phase 2 of the development and implementation of a robust IPM programme. *Report of contract work undertaken for HDC*, June 2008, 37 pp.

Jacobson, R.J. (2009). Sweet pepper: Short term solutions for leafhopper and aphid infestations. *Report of contract work undertaken for HDC*, November 2009, 59 pp

Jacobson, R.J. (2011). Organic tomato; Contingency plans for the control of *Nesidiocoris tenuis*. *Report of contract work undertaken for HDC*, January 2011, 34 pp

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

Jacobson, R.J. & Morley, P (2008). Tomato: Population growth of pests on speciality cultivars. *Report of contract work undertaken for HDC*, March 2008, 65 pp

Jacobson, R.J. and Morley, P (2009). Organic tomato: Development and implementation of a robust pesticide-free IPM programme. Horticultural Development Company Final report for project PC 240, March 2009, 69pp

Jacobson, R.J. and Morley, P (2010). Organic tomato: Phase 1 of contingency plans for the control of *Tuta absoluta* and *Nesidiocoris tenuis.* Horticultural Development Company Final report for project PC 302, July 2010, 51pp.

Jacobson, R.J. and Howlett, P. (2012). Tomato: Phase 3 of contingency plans for the control of *Tuta absoluta*. Horticultural Development Company Final report for project PC 302b, December 2012, 22pp.

Jacobson, R.J. and Howlett, P. (2013). Tomato: Phase 4 of the development of a robust IPM programme for *Tuta absoluta*. Horticultural Development Company Final report for project PC 302d, December 2013, 23pp.

