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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.

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GROWER SUMMARY

Headline

Tyrophagus similis was confirmed as the mite causing damage to outdoor spinach crops. This 'localised' sporadic pest is associated with field patches that have high amounts of partly-degraded organic matter. None of the acaricide products tested completely eliminated the mites.

Background

During late summer-autumn 2010, outbreaks of mites caused damage to outdoor spinach crops in southern England. The outbreaks occurred at several locations. The problem has occurred previously but is sporadic in nature. The objectives of this project were to:

1. Confirm the identity of the mites causing damage to spinach crops.

2. Develop a laboratory culturing technique to provide mites for experiments on control

3. Collate and summarise information on the biology of the mites that would be relevant to predicting and controlling infestations

4. Identify potential control methods and test them on a small scale

Summary

Objective 1 Confirm the identity of the mites causing damage to spinach crops.

Despite the very wet weather in summer 2012, small samples of mites were obtained from field-grown spinach (provided by growers or field-collected by Agrii or Warwick Crop Centre staff) on three occasions and these were sent to Fera for identification. All samples contained *Tyrophagus similis*, confirming the identity of this pest.

Objective 2 Develop a laboratory culturing technique to provide mites for experiments on control

Attempts to produce a laboratory population of *T. similis* were unsuccessful and so attempts were made to establish an infestation in two locations at Wellesbourne, where organic matter was relatively high and spinach was sown. The first location was established in summer 2012 (Dutch lights) and sequential sowings of spinach were made. The plants were not harvested and the organic matter was left to decompose over winter; more spinach sowings were made in 2013. A second location (12 micro-plots) was sown with spinach in 2013 and the area was 'inoculated' with infested plant material collected in from a crop in Kent in early September 2013.

The areas were sampled from time to time by taking soil samples and putting the soil in polythene bags into which a filter paper 'trap' was placed. Traps were composed of a piece of folded moistened filter paper containing small amounts of dry yeast as used by Japanese researchers. Any mites that were 'captured' were recorded but not identified to species level. Mites were 'captured' from samples of soil taken from the micro-plots in September and October and from the Dutch Lights area in September.

Some potted spinach plants which were infested with mites when sampled in September 2013 were retained over the winter in a polytunnel. One pot was destructively sampled on 6 January 2014 and 2 mites were found on 6 plants.

Objective 3 *Collate and summarise information on the biology of the mites that would be relevant to predicting and controlling infestations.*

A literature review was undertaken and key points are as follows:

Tyrophagus similis appears to be quite widely distributed world-wide and the main studies on it have been done in Japan and the Yemen. In Japan, mites damage spinach grown in greenhouses in particular. The mites penetrate spinach shoots and feed on young leaves. The shoots are readily accessible because they are close to the soil surface. As the plants grow, the damaged leaves show small holes and/or deformation.

Tyrophagus similis is one of a number of species of small arthropods that have an important role in mineral turnover, vegetation succession and decomposition of organic matter. The pest has been observed to feed mainly on organic fertilizers, plant detritus, small organisms and the dead bodies of soil arthropods. The development of *T. similis* populations on organic wastes and immature composts may be due to their feeding on fungi that occur in these materials. Generally, the growth of fungi is greater on organic wastes and immature composts than on mature ones, because mature composts have already been decomposed by several forms of microorganisms. *Tyrophagus similis* lives in, and on, soil at depths of 0-5 cm and numbers decrease with increasing depth.

The low temperature threshold for development for *T. similis* is 7°C and females can lay several hundred eggs in their lifetime. Egg viability of *T. similis* declined at temperatures above 30°C, female survival was reduced at temperatures above 35°C, and of *T. similis* maintained at 10, 15, 20 and 25°C, those maintained at 10°C had the greatest fecundity during their lifetime.

In Japanese research on spinach crops grown in greenhouses, the *T. similis* population in the soil remained at low levels during the hot season from May to September, increased rapidly in October and November, remained at a high level during the cool season from December to February, and further increased in April. The mites, which were in the soil, infested the spinach plants mostly in late autumn and early spring. The high temperatures in the greenhouses from spring to early autumn were considered to be one of the main causes of population decrease. It was hypothesised that the mites initially increase in number on, or in, cultivated soil that is rich in organic matter and then invade the spinach plants. It seemed likely that the mites use the spinach plants as a shelter from harsh physical conditions in the surface soil (e.g. high temperature and dryness) in the warm season, because few mites inhabited spinach plants during the cool season even when mite density in the soil was relatively high. If this is the case, then the movement of the mites to the spinach plants might not be primarily to obtain food. It seemed to the Japanese researchers that *T. similis* was more closely associated with the soil than with spinach plants, because it was feeding on and living in various types of organic matter in the soil.

If the mites live mainly in the soil, attempts to control the mites by spraying the plants with pesticide might be expected to have a limited effect. In Japan, attempts have been made to control *Tyrophagus similis* with agrochemicals. Such agrochemicals have been used generally after an increase in damage is observed, but in many cases, their effects have been unsatisfactory. This suggests that the chemicals had little direct contact with the mites in both the soil and spinach plants.

Apart from temperature, dryness of the soil surface and tillage after cultivation might reduce mite numbers temporarily. Solar heating and hot water treatment may be effective for controlling *T. similis* in the soil in greenhouses. To effectively control the mites, it may be necessary to keep the temperature above 35°C for several hours. Cultural approaches to reduce damage to spinach could be by: (1) Reducing the use of organic fertilizers during the mite season, (2) removing plant residues on the soil before cultivation, and (3) reducing the use of immature organic materials, because they increase fungi that are suitable food for *T.*

similis. Other mites are certainly likely to be predators of *T. similis,* but an effective biological control system has not been developed.

It is likely that the target for control should be mite populations in the soil rather than the mites in the spinach crop and there may be many mites in the soil at times when there are none on the plants. Thus, surveying mite numbers in the soil may be of value. This can be done using Tullgren funnels to extract mites from soil samples, although this method is labour-intensive. A Japanese group developed a relatively simple 'trap' for monitoring mites in soil. The trap is a piece of folded moistened filter paper containing a small amount of dry yeast. Rather than deploy these traps in the field, the researchers took samples of soil from the field, placed them in polythene bags and then the traps were placed on the surface of the soil in each sample bag. The sample bags were sealed and the traps were checked at intervals and the mites identified and counted. When this approach was compared with the use of Tullgren funnel samples, higher numbers of mites were obtained.

Objective 4 Identify potential control methods and test them on a small scale

Potential control methods highlighted by the literature review include:

- Control with pesticides
    - This depends on a suitable active ingredient being available and approved for spinach.
    - The review indicated that the mites may be a difficult target and that soil treatment might be more effective than treatment of the plants (which may be too late). Soil treatment requires an effective method of application.
- Biological control
    - There might be a suitable control agent available commercially.
    - However, this would be a very expensive, and potentially labour-intensive, way of controlling a sporadic pest.
    - Efficacy has not been demonstrated.
- Physical control
    - Cultivation may reduce mite populations for one or more reasons.
    - Heating the soil (with black polythene?) may be effective.
    - Irrigation may make the soil environment less hostile at certain times and prevent the mites infesting the spinach plants.
- Cultural control
    - Management of organic material in the soil may be key.
- Monitoring

- Use of the filter paper trap approach may highlight large mite populations.
- A pheromone has been identified in female *T. similis* which acts both as an alarm pheromone and a female sex pheromone. It is possible that, in the right concentration, it could be deployed as a monitoring tool.

Small-scale acaricide trial

A total of 46 pots of infested spinach plants taken from a field in Kent in September 2013 (Figure 1) were used in a small-scale efficacy trial. The treatments were: Masai (20% tebufenpyrad) 1.8l/ha; Dynamec (18g/l abamectin) 0.5l/ha and Spruzit (4.59g/l pyrethrins) 0.5l/ha. All in the equivalent of 300l/ha water. The pots were destructively sampled after treatment. Mite numbers were low, but none of the treatments completely eliminated the mites.

Figure 1 Mite-infested spinach plants collected from Kent in September 2013.

Discussion

Although weather conditions did not favour research on this pest in summer 2012, sufficient numbers were obtained to confirm its identity and the literature review revealed some useful background information. Sufficient mites were collected in September 2013 to undertake a small-scale acaricide trial.

Tyrophagus similis is not an easy pest to work on because of its sporadic nature and because it is likely that it is more closely associated with the soil (organic matter) than the crop. Possible approaches to continue investigating this pest problem are:

- To keep trying to establish a small field infestation. Application of organic matter is probably the key. It may then be possible to get a better handle on the conditions that lead to damage in spinach. It is likely that there are ‘organic matter’, ‘cultivation’ and ‘weather’ factors involved.
- The ‘solution’ to this pest problem is likely to be a combination of predicting the ‘risk’ and managing the crop/cultivation to minimise damage. It is doubtful that an effective pesticide treatment will be identified and, in any case, by the time damage is observed it may be too late. The ‘risk’ is undoubtedly related to the amount of organic matter (in a certain condition?). Are certain crops in the rotation likely to increase this?
- Traps may be one way of predicting the risk and pheromone traps might be more selective (are they available commercially?) – but how far ahead is it possible to do this? Do populations multiply rapidly under certain conditions where mites are at very low (undetectable) infestations earlier on? Does a grower have the opportunity to ‘change fields’ if a high risk field was identified early on?
- It may be best to undertake a ‘low-key’ fairly long-term project that tries to build up a field infestation and uses resources (e.g. infested crops) as they become available. Pheromone traps (if available) might help with surveys of commercial crops and it might be possible over time to build up a picture of the risk factors. In parallel, if a field infestation were established it would be possible to look at cultural and other approaches to control. It also depends how important this problem is and therefore how much a grower might be willing to ‘spend’ on controlling it?

Financial Benefits

The results of this project contribute to an understanding of this damaging, but sporadic, pest and identify possible methods of predicting and controlling infestations.

Action Points

- Growers should aim to minimise the amount of partly-degraded organic matter in the soil prior to sowing a spinach crop.

SCIENCE SECTION

Introduction

During late summer-autumn 2010, outbreaks of mites caused damage to outdoor spinach crops in southern England. These outbreaks occurred at several locations. The problem has occurred previously (Chris Wallwork, Agrii, personal communication) but it is sporadic in nature. Samples of infested spinach were sent to Wellesbourne and attempts were made to:

- Make a basic identification
- Culture the mites in the laboratory

It was thought that the mites were a species of *Tyrophagus*, possibly *T. similis* but there was a need for confirmation of this identification. *Tyrophagus similis* is a pest of spinach in Japan and there are a number of papers on its biology and control which could provide useful background information. For example, Kasuga and Amano (2000b) found that egg hatch by *T. similis* declined sharply at temperatures above 30°C, and that female survival was limited at temperatures above 35°C. They also found that of *T. similis* maintained at 10, 15, 20 and 25°C, those maintained at 10°C had the greatest lifetime fecundity and that the developmental threshold of *T. similis*, i.e., the temperature at which development ceases, was 7°C. In a later paper (Kasuga & Amano, 2003), they suggested that the mites survive in the soil feeding on detritus (so were not obligate plant feeders) and travel into the spinach buds when conditions at the soil surface become unfavourable (i.e. too hot or dry).

The objectives of this project were to:

1. Confirm the identity of the mites causing damage to spinach crops.

2. Develop a laboratory culturing technique to provide mites for experiments on control

3. Collate and summarise information on the biology of the mites that would be relevant to predicting and controlling infestations

4. Identify potential control methods and test them on a small scale

The very wet weather conditions in the summer of 2012 meant that it was impossible to achieve objectives 2 and 4 within the timescale of the project and so an extension to the project was agreed so that further work could be undertaken in 2013.

Materials and methods

1. Confirm the identity of the mites causing damage to spinach crops.

This was done by asking growers for samples from infested crops and sending them for verification of identity by mite taxonomists at Fera.

2. Develop a laboratory culturing technique to provide mites for experiments on control

This followed from the initial attempt to culture the mites prior to the start of the project. In 2012 attempts were made to do this using pot-grown spinach in controlled environment rooms in the Insect Rearing Unit at Warwick Crop Centre.

Since attempts to produce a laboratory population were not successful, attempts were made to establish an infestation in two locations at Wellesbourne, where organic matter is relatively high and spinach was sown. The first location was established in summer 2012 (Dutch lights) and sequential sowings of spinach were made. The plants were not harvested and the organic matter was left to decompose over winter; more spinach sowings were made in 2013. A second location (12 micro-plots) was sown with spinach in 2013 and the area was ‘inoculated’ with infested plant material collected in early September 2013. These areas have been sampled from time to time by taking soil samples and putting the soil in polythene bags into which a filter paper ‘trap’ is placed. The trap is a piece of folded moistened filter paper containing a small amount of dry yeast as used by Japanese researchers (Kasuga *et al.,* 2005). Any mites ‘captured’ were recorded but not identified to species.

3. Collate and summarise information on the biology of the mites that would be relevant to predicting and controlling infestations

A literature survey was undertaken and all relevant information was summarised, highlighting any information that might help growers to predict or avoid infestations.

4. Identify potential control methods and test them on a small scale

The aim was to use the literature, conversations with agrochemical companies and other experts to identify potential control methods, chemical or otherwise and test them on a small scale.

Results

1. Confirm the identity of the mites causing damage to spinach crops.

The summer of 2012 was extremely challenging because of the prolonged period of rainfall and very wet conditions in the field. Small samples of mites were obtained from field-grown spinach (provided by growers or field-collected by Agrii or Warwick Crop Centre staff) on three occasions and these were sent to Fera for identification. All samples contained *Tyrophagus similis*, confirming the identity of this pest.

In early August 2013 soil samples (upper layer) were taken from three locations at Warwick Crop Centre (carrot crop, an area where spinach was grown in 2012 and the stubble of an early pea crop). Of these, the samples taken from the stubble of an early pea crop yielded a number of mites, indicating the potential relationship between decaying organic matter and mites.

There were no reported incidents of mite damage in early summer 2013 (in particular, Chris Wallwork and colleagues from Agrii were looking out for them). However, Chris identified an infestation in a commercial crop of spinach in Kent in early September 2013 and Rosemary Collier went there the next day to collect some. She brought back quite a large amount of plant material (rooted plants mainly) and also some soil from the infested crop and from the cereal stubble in the field next door. The land was rented and is part of a cereal rotation. The plants/soil were used in several ways. Some of the plants were potted up with additional soil (Figure 2) and were used in an acaricide trial and some were retained in a polytunnel over winter. The ‘filter paper trap’ approach (Kasuga *et al.,* 2005) was used to sample the soil collected from the spinach crop and from the adjacent stubble. Mites were recovered from the spinach soil but not from the stubble.

Figure 2 Mite-infested spinach plants collected from Kent in September 2013.

2. Develop a laboratory culturing technique to provide mites for experiments on control

To date, attempts to produce a laboratory population of *T. similis,* either on spinach plants or on yeast powder (Maruno *et al.,* 2012) have been unsuccessful and so attempts were made to establish an infestation in two locations at Wellesbourne, where organic matter is relatively high and spinach was sown. The first location was established in summer 2012 (Dutch lights) and sequential sowings of spinach were made. The plants were not harvested and the organic matter was left to decompose over winter; more spinach sowings were made in 2013. A second location (12 micro-plots) was sown with spinach in 2013 and the area was 'inoculated' with infested plant material collected in early September 2013 (above).

These areas have been sampled from time to time by taking soil samples and putting the soil in polythene bags into which a filter paper 'trap' is placed (Kasuga *et al.,* 2005). Any mites 'captured' were recorded but not identified to species. Mites were 'captured' from samples of soil taken from the micro-plots in September and October and from the Dutch Lights area in September.

One of the potted plants that were retained over the winter in a polytunnel was destructively sampled on 6 January 2014 and 2 mites were found on 6 plants.

3. Collate and summarise information on the biology of the mites that would be relevant to predicting and controlling infestations

Information on *T. similis* from the literature is summarised below:

Distribution

Tyrophagus similis appears to be quite widely distributed world-wide and the main studies on it have been undertaken in Japan (papers by Kasuga and colleagues) and the Yemen (Al-Safadi, 1991) (who also worked at the University of Birmingham).

Damage

In Japan, mites of the genus *Tyrophagus* damage spinach grown in greenhouses in particular (Nakao 1989). The mites penetrate spinach shoots and feed on young leaves. The shoots are readily accessible because they are close to the soil surface. As the plants grow, the damaged leaves show small holes and/or deformation. Mites of this genus have spread throughout the commercial spinach growing areas of Japan and the problem has increased over time (Kasuga and Amano 2000a). They can also damage spinach seed during germination (Kasuga and Amano, 2006).

Tyrophagus similis Volgin is the mite species that causes the most damage to spinach in Japan (Kasuga and Amano 2000a). Damage by *T. similis* is mostly observed in greenhouses in early spring and late autumn when greenhouse temperatures are generally moderate (Kasuga & Amano, 2003). *Tyrophagus similis* can also damage melon, cucumber, pumpkin and maize (Nakao and Kurosa, 1988). Whilst *T. similis* is abundant in the Yemen, its pest status there is less clear (Al-Safedi, 1987).

Biology

Tyrophagus similis is one of a number of species of small arthropods that has an important role in mineral turnover, vegetation succession and is a decomposer of organic matter in combination with microflora (Al-Safedi, 1987). This species has been found in grassland, soil, plants, old hay, chaff, duck and bee nests (Hughes, 1976) and greenhouses. In greenhouses, *T. similis* has been observed to feed mainly on organic fertilizer, plant detritus, bryophytes and the dead bodies of soil arthropods (Kasuga & Amano, 2003). More recently, Kasuga and Honda (2006) fed *Tyrophagus similis* on three organic wastes (cattle faeces, sawdust, and rice straw), an organic fertilizer (rapeseed meal), three composts (made from cattle faeces, rice husks, and rice straw), three fungi (*Fusarium oxysporum*, *Pythium aphanidermatum*, and *Rhizoctonia solani*) and eight vegetables (lettuce, cucumber, komatsuna, spinach, pak choi, garland chrysanthemum, Welsh onion, and tomato), to determine their suitability as food, using the fecundity of females as an indicator. Rapeseed meal, fungi, and most vegetables were suitable food sources. The organic wastes and composts were unsuitable. *Tyrophagus similis* lives in, and on, soil at depths of 0-5 cm and numbers decrease with increasing depth (Kasuga & Amano, 2005).

The two main research groups working on this species have studied its basic biology and responses to temperature. Al-Safedi (1987) found that female mites laid an average of 18 eggs, singly or in small clusters and that at 21°C the complete life-cycle took 10-12 days. It is difficult to reconcile some of the information from this study with the more detailed work undertaken in Japan (Kasuga and Amano, 2000b). Kasuga and Amano found that the low temperature threshold for development (t_0) for *T. similis* is 7°C and that females can lay several hundred eggs in their lifetime (Table 1), laying as many eggs at 10 and 15°C as at 20 and 25°C (Kasuga & Ammano, 2000b). The numbers of eggs laid per day during the oviposition period were in the range of 8-11 (Table 1). A temperature of 30°C was not suitable for development of the immature stages, which in this case agrees with the conclusions of Al-Safedi (1991). Mites survived better at relative humidities of 76, 87 and 100% than at 53 and 66% (Kasuga & Ammano, 2000b).

Table 1. Developmental parameters for *T. similis* (from Kasuga and Amano, 2000b).

Temperature (°C)	**Total longevity of adult (days)**	**Lifetime fecundity (days)**	**Mean generation time (days)**	**Mean number of eggs laid per day during oviposition period**
10	124	663	102	8
15	83	547	61	11
20	42	335	38	10
25	22	149	22	10

In the Japanese research in greenhouses, the *T. similis* population in the soil remained at low levels during the hot season from May to September, increased rapidly in October and November, remained at a high level during the cool season from December to February, and further increased in April (Kasuga and Amano, 2003). The mites, which were in the soil, infested the spinach plants mostly in late autumn and early spring. The high temperatures in the greenhouses from spring to early autumn were considered to be one of the main causes of population decrease, even though the soil must buffer the mites from direct sunlight. These findings were consistent with the previous laboratory observations (Kasuga and Amano, 2000b) where they found that egg viability of *T.similis* declined at temperatures above 30°C, that female survival was reduced at temperatures above 35°C, and that of the *T. similis* maintained at 10, 15, 20 and 25°C, those maintained at 10°C had the greatest fecundity during their lifetime.

Kasuga and Amano (2003) hypothesised that the mites initially increase in number on, or in, cultivated soil rich in organic matter and then invade the spinach plants. It seemed likely to them that the mites used the spinach plants as a shelter from harsh physical conditions in the soil surface (e.g. high temperature and dryness) in the warm season, because few mites inhabited spinach plants during the cool season even when mite density in the soil was relatively high (approximately 30 mites per 100 cm^3 of soil). If this is the case, then the movement of the mites to the spinach plants might not be primarily to obtain food and it seemed that *T. similis* was more closely associated with the soil than with spinach plants because it was feeding on, and living in, various types of organic matter in the soil. Thus, if the mites mainly live in the soil, attempts to control the mites by spraying the plants with pesticide would be expected to have a limited effect.

Following their study on the best diets for *T. similis*, Kasuga & Honda (2006) altered their view slightly in terms of organic wastes and hypothesised that the increase of *T. similis* on organic wastes and immature composts may be due to their feeding on fungi that occur in these materials. Generally, the growth of fungi is greater on organic wastes and immature composts than on mature ones, because mature composts have already been decomposed by several forms of microorganisms.

Control

In Japan, attempts have been made to control *Tyrophagus similis* with agrochemicals. For example, Dichlorvos emulsifiable concentrate and DCIP (bis(2-chloro-1-methylethyl) ether) granules have been approved for use to control this species in Japan. Such agrochemicals have been used generally after an increase in damage is observed, but in many cases, their effects have been unsatisfactory. This suggests that the chemicals in both the soil and spinach plants had little direct contact with the mites (Kasuga and Amano, 2002; 2003).

Cultural control

Apart from temperature, dryness of the soil surface and tillage after cultivation might reduce mite numbers temporarily. Solar heating and hot water treatment may be effective for controlling *T. similis* in the soil in greenhouses. To effectively control the mites, it may be necessary to keep the temperature above 35°C for 5 hours (Kasuga and Amano 2000b). The study by Kasuga & Honda (2006) on the 'best' diet for *T. similis* suggested ways to reduce damage to spinach by: (1) Reducing the use of organic fertilizers (such as rapeseed meal in their case) during the mite season, (2) removing plant residues on the soil before spinach cultivation, and (3) reducing the use of immature organic materials, because they increase fungi that are suitable for *T. similis*.

Biological control

Other mites are certainly likely to be predators of *T. similis* (Al-Safedi, 1987). For example, *Hypoaspis aculeifer* was investigated as a predator (Kasuga et al., 2006). It can eat a whole range of small animals and in laboratory tests it was possible to rear it on *T. similis*, although *T. similis* was not the 'best' host. In addition, its optimum temperature range is higher than that of *T. similis* (Kasuga et al., 2006), so it might not be a suitable predator in the field in the UK. The same thing was true for another predatory mite investigated in Japan, *Hypoaspis yamauchii*, which was a predator of *T. similis* at 20-25°C but not at 15 or 30°C (Saito, 2012).

Timing of treatments

The results of a study on control with agrochemicals suggested to Kasuga & Amano (2003) that the mites could be controlled successfully by application of agrochemicals in the autumn. They considered that an effective method of chemical control would be spraying the soil or mixing granules in the soil. However, it would be difficult to determine the threshold at which control measures should begin because there is a time lag between mite feeding and the subsequent spinach damage and certainly if control measures are not begun until spinach damage is apparent, it may be too late.

It is likely that the target should be populations in the soil rather than the mites in the spinach, as the latter are probably relatively inaccessible to insecticides. In addition, there may be many mites in the soil at times when there are none on the spinach plants. Thus, surveying mite numbers in the soil is of value because mite outbreaks in the soil often cause spinach damage. Kasuga & Amano (2003) used Tullgren funnels to extract mites from soil samples, but this method is labour-intensive. Kasuga *et al.* (2005) developed a relatively simple 'trap' for monitoring mites in soil. The trap is a piece of folded moistened filter paper containing a small amount of dry yeast. Rather than deploy these traps in the field, Kasuga *et al* took samples of soil from the field, placed them in polythene bags and then the traps were placed on the surface of the soil in each sample bag. The sample bags were sealed and the traps were checked at intervals and the mites identified and counted. When this approach was compared with the use of Tullgren funnel samples, higher numbers were obtained.

A pheromone has been identified in female *T. similis* which acts both as an alarm pheromone and a female sex pheromone (Maruno et al., 2012). It is possible that, in the right concentration, it could be deployed as a monitoring tool.

4. Identify potential control methods and test them on a small scale

Potential control methods highlighted by the literature review include:

- Control with pesticides
    i. This depends on a suitable active ingredient being available and approved for spinach.
    ii. The review indicates that the mites may be a difficult target and that soil treatment might be more effective than treatment the plants (which may be too late). Soil treatment requires an effective method of application.
- Biological control
    i. There might be a suitable control agent available commercially.
    ii. However, this would be a very expensive and potentially labour-intensive way of controlling a sporadic pest.
    iii. Efficacy has not been demonstrated.
- Physical control
    i. Cultivation may reduce mite populations for one or more reasons.
    ii. Heating the soil (with black polythene?) may be effective
    iii. Irrigation may make the soil environment less hostile at certain times and prevent the mites infesting the spinach plants
- Cultural control
    i. Management of organic material in the soil may be key.
- Monitoring
    i. Use of the filter paper trap approach may highlight large mite populations.

ii. As a pheromone has been identified in female *T. similis* which acts both as an alarm pheromone and a female sex pheromone, it is possible that, in the right concentration, it could be deployed as a monitoring tool.

Small-scale acaricide trial

A total of 46 pots of infested spinach plants taken from the field in Kent in September 2013 were used in a small-scale efficacy trial. The treatments were: Masai (20% tebufenpyrad) 1.8l/ha; Dynamec (18g/l abamectin) 0.5l/ha and Spruzit (4.59g/l pyrethrins) 0.5l/ha. All were applied in the equivalent of 300l/ha water. The pots were destructively sampled after treatment.

Mite numbers were low (Table 2), but none of the treatments completely eliminated the mites.

Table 2 Number of pots of infested spinach treated and number of mites recovered post-treatment.

Treatment	**Number of pots**	**Mean number of mites per pot post-treatment**
Untreated control	13	0.77
Masai	14	1.71
Dynamec	9	1.11
Spruzit	10	0.40

Discussion

Although weather conditions did not favour research on this pest in summer 2012, sufficient numbers were obtained to confirm its identity and the literature review revealed some useful background information. Sufficient mites were collected in September 2013 to undertake a small-scale acaricide trial.

Tyrophagus similis is not an easy pest to work on because of its sporadic nature and because it is likely that it is more closely associated with the soil (organic matter) than the crop. Possible approaches to continue investigating this pest problem are:

- To keep trying to establish a small field infestation. Application of organic matter is probably the key. It may then be possible to get a better handle on the conditions that lead to damage in spinach. It is likely that there are 'organic matter', 'cultivation' and 'weather' factors involved.
- The 'solution' to this pest problem is likely to be a combination of predicting the 'risk' and managing the crop/cultivation to minimise damage. It is doubtful that an effective pesticide treatment will be identified and, in any case, by the time damage is observed it may be too late. The 'risk' is undoubtedly related to the amount of organic matter (in a certain condition?). Are certain crops in the rotation likely to increase this?
- Traps may be one way of predicting the risk and pheromone traps might be more selective (are they available commercially?) – but how far ahead it is possible to do this? Do populations multiply rapidly under certain conditions where mites are at very low (undetectable) infestations earlier on? Does a grower have the opportunity to 'change fields' if a high risk field was identified early on?
- It may be best to undertake a 'low-key' fairly long-term project that tries to build up a field infestation and uses resources (e.g. infested crops) as they become available. Pheromone traps (if available) might help with surveys of commercial crops and it might be possible over time to build up a picture of the risk factors. In parallel, if a field infestation were established it would be possible to look at cultural and other approaches to control. It also depends how important this problem is and therefore how much a grower might be willing to 'spend' on controlling it?

Conclusions

- The pest mite causing damage to outdoor spinach crops was confirmed as *Tyrophagus similis.* This species feeds mainly on material and organisms associated with organic matter in the soil and may damage spinach as a consequence of its need to avoid adverse soil conditions.
- The 'risk' is undoubtedly related to the amount of organic matter in the crop although there is insufficient information to describe the conditions that lead to outbreaks.
- It is very doubtful that pesticide treatment will be effective and, in any case, by the time damage is observed it may be too late to apply such a treatment.
- To obtain more information on this pest it may be best to undertake a 'low-key' fairly long-term project that tries to build up a field infestation and uses resources (e.g. infested crops) as they become available. Pheromone traps (if available) might help with surveys of commercial crops and it might be possible over time to build up a

picture of the risk factors. In parallel, if a field infestation were established it would be possible to look at cultural and other approaches to control.

Knowledge and Technology Transfer

There have been no knowledge transfer activities to date.

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