FACTSHEET 24/16

Hardy Nursery Stock

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Jude Bennison and David Talbot, ADAS and Tom Pope, Harper Adams University

Vine weevil control in hardy nursery stock

Vine weevil (*Otiorhynchus sulcatus*) remains the number one pest of container-grown hardy nursery stock. This factsheet provides information on the biology and damage caused by vine weevil adults and larvae and explains the various strategies that can be adopted to control the pest.

Figure 1. Close up of adult vine weevil and associated leaf notching

Action points

Monitoring for adult weevils

- Check for adult activity and damage on susceptible plant species from April onwards (Figure 1).
- Look for adults at night with the aid of a torch on shoot tips or gently shake the plants onto a white sheet of paper to dislodge and identify them.
- Plant genera such as *Euonymus* or *Primula* can be used as indicator plants. Remove any notched leaves once recorded, so new notching can be identified.
- Check for adults during the day under containers, container rims or in plant debris, or use purpose-made refuges placed among the plants.

Monitoring for weevil larvae

- Check a sample of bought-in susceptible young or finished plants for larvae.
- Check older susceptible plants for signs of stress or wilting.
- Check around roots and crowns for larvae by knocking plants out of their containers and searching through the growing media. Larvae can potentially be present all year round.

Cultural control

- Place unsaleable plants and growing media badly infested with vine weevil larvae into covered containers for disposal off site.
- Control weeds in or around glasshouses, polythene tunnels and production beds that could provide alternative hosts for vine weevil.
- Remove plant debris between crops to reduce refuge sites for adult vine weevils.

Biological control

- Plan biological control strategies for vine weevil within an integrated pest management programme.
- If using entomopathogenic nematodes, apply them between August and October to control larvae hatching from summer and autumn-laid eggs. Two sequential applications may be needed in mild autumns when egg laying continues later into the season. Consider another application in April if live overwintered larvae are found. Measure growing media temperatures to assist with nematode species selection.
- If considering using *Metarhizium anisopliae* (Met52 Granular Bioinsecticide) incorporation into the growing media, this is likely to be more effective in crops potted through the spring/summer than in the autumn due to its temperature requirements.

Chemical control

- Select a plant protection product (foliar application, drench or incorporation) with the least negative effects on the biological control agents used against other pests.
- Consider foliar application(s) against adult weevils in April/May (overwintered adults) or June/July (new adults) if monitoring indicates activity. Ideally, these will help to control adult populations before they commence laying eggs.
- Consider the use of a persistent granular insecticide for incorporation into growing media. Be aware of the current EC restrictions on the use of certain neonicotinoid insecticide products.

Introduction

The vine weevil (*Otiorhynchus sulcatus*) is native to temperate areas of Europe, including the UK (Figure 1). In the wild, it can be found in hedgerows and woodland margins feeding on a range of host plants, including trees such as yew and many herbaceous and annual plant species. Vine weevil populations have become established on many nurseries growing hardy nursery stock for several reasons: many of the plant species grown are suitable hosts, more container-grown plants are now grown under protection, which favours the pest, the various growing media blends used in container production are very suitable for egg survival and larval development (Figure 2) and there are now very few options for effective and persistent chemical control. In particular, there are now restrictions on the few remaining persistent insecticides that can be incorporated into growing media.

Biological control methods are available, including an entomopathogenic fungus and various nematode species, however, there is a lack of industry confidence in the reliability of control achieved by the fungus, and the use of nematode drenches can be unpopular due to the time-consuming nature of the application process.

Figure 2. Vine weevil larvae in the root ball of *Euonymus*

The industry is under increasing pressure not only to reduce the use of plant protection products but also to produce pest-free plants, and the presence of adult feeding damage on the foliage or even a single vine weevil larva within a root ball can lead to product rejection.

Biology and plant damage

Adults

Vine weevils are all female and so reproduce without mating (parthenogenetically). This means that only one weevil is required to start an infestation.

Adult weevils are 8.5–11.5mm in length (Figure 1). The adult weevils are dull black or dark grey in colour but with short tufts of orange hairs on the wing cases, giving the weevils a speckled look. The wing cases are fused together and so adult weevils are unable to fly and instead walk from one area to another.

When disturbed, adult weevils 'play dead' by lying still with their legs curled up and, as they often occur in leaf debris or under containers or trays, they are easily missed. They are usually only active at night but may occasionally be seen during the day.

Adult weevils remain active within host crops for as long as temperatures remain warm enough. Some adults may overwinter in leaf litter and in other sheltered areas. The number of adults successfully overwintering is determined by the severity of the winter. Overwintered adults may be seen from as early as April and these individuals may start feeding and laying eggs soon after they become active. Most adult weevils, however, emerge from pupae in the soil or growing media after completing the final stages of development in the spring. These young adults emerge over an extended period, usually from May/June onwards. Young adult weevils feed for approximately one month before commencing egg laying from June onwards. Adult feeding results in characteristic leaf notching (Figure 3). Both adults and larvae can feed on many plant species.

Each adult can lay over 300 eggs outdoors and are likely to lay more eggs where they are found under protection. Under optimum conditions, a single weevil can lay 1,600 eggs during its lifespan. Egg laying may start as early as April (by overwintered adults) and continue for as long

as conditions remain favourable, often into October and November. Eggs are laid at night, typically into cracks in the growing medium, but also occasionally on the surface, or on the leaves, stems and corms of host plants.

Figure 3. Typical leaf notching symptoms associated with adult vine weevil feeding

Eggs

Eggs are spherical and 0.8mm in diameter. When first laid, the eggs are white but soon become chestnut brown in colour (Figure 4) and are very hard to see within the growing medium. The time taken for the eggs to hatch is temperature dependent; at around 20°C, egg hatch occurs after approximately two weeks. This period is reduced at higher temperatures and extended at lower temperatures.

Figure 4. Vine weevil eggs are white when first laid, then turn brown prior to hatching

Larvae

The larvae that hatch out of the eggs from late June onwards are white (larvae may appear off-white when they feed on some nursery stock subjects), legless, have a chestnut brown head capsule and often hold themselves in a C-shape (Figure 5). Young larvae tend to feed on the fine fibrous roots of the root ball of container-grown plants, while older larvae may burrow into roots, plant crowns, corms and rhizomes and can 'girdle' stem bases. Once larvae are inside plants, they become much more difficult to control. The larvae moult several times over the summer and early autumn, reaching a maximum size of about 12mm.

Like the adults, larvae in the growing media will remain active and continue to feed as long as conditions remain favourable. In outdoor situations, larvae typically continue to feed until the end of October but, under protection, this period may be extended. They stop feeding with the onset of low temperatures, but even freezing conditions are unlikely to kill them. In spring, feeding may commence again until the larvae pupate. Plant damage or water stress symptoms often do not show until spring when the remaining roots are eaten or stem bases are girdled. Severe damage can lead to plant collapse and death.

Figure 5. Vine weevil larva with brown head capsule and no legs

Pupae

Pupae are creamy white but, unlike the larvae, the folded up legs can be seen on the underside of the body (Figure 6). Pupae are typically found within cells made of the soil or growing medium in which the plant is grown. When disturbed, the pupae may move slightly. New adults emerge two to three weeks after pupation begins.

Figure 6. Vine weevil pupa with legs folded beneath the body

The life cycle of vine weevil under UK conditions is shown in Figure 7. Outdoors, this typically takes between nine and 11 months; with the greatest time being spent as a larva, feeding on roots. In heated production areas, such as propagation houses, the life cycle may be compressed and take as little as four months, and all stages of the vine weevil may be present at the same time. This means that, potentially, up to two generations may be completed within the year.

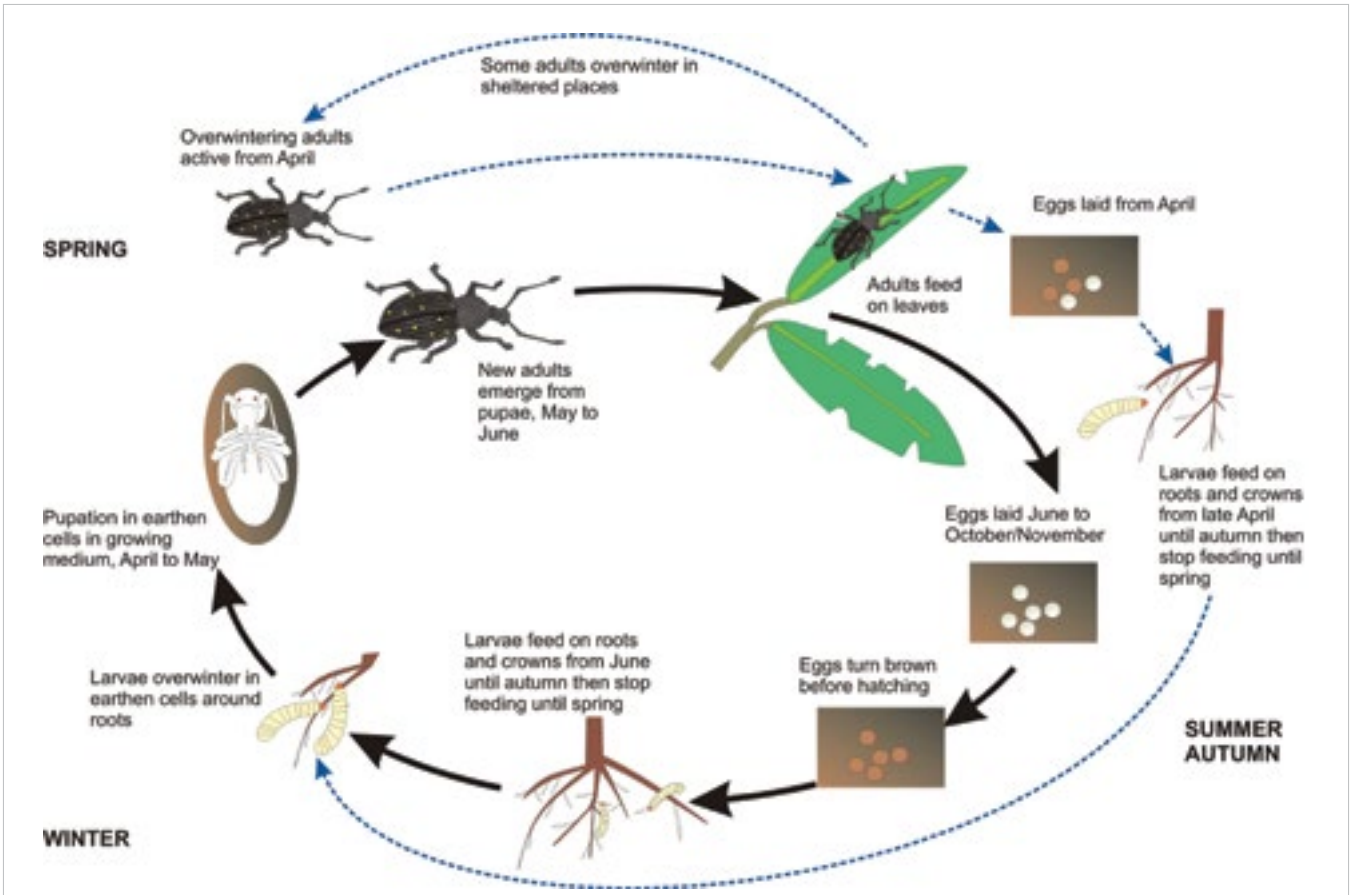

Figure 7. Life cycle of vine weevil under UK conditions

Sources of infestation

Potential sources of infestation in container-grown hardy nursery stock crops include:

- Resident overwintered vine weevil larvae in old liners or plants not sold the previous year or in other sheltered areas on the nursery.
- Adults moving into container areas from surrounding hedgerows, trees or outdoor stock beds.
- Eggs or larvae in bought-in plugs, liners or other plants.

Vine weevil behaviour and monitoring

By understanding the behaviour of the pest, it is possible to monitor adult weevil infestations. Defra-funded studies (project PS2140) using tiny electronic tags (Figure 8) have shown that most adult weevils move only short distances, for example, just 1.5m in seven days within a favourable *Euonymus* crop.

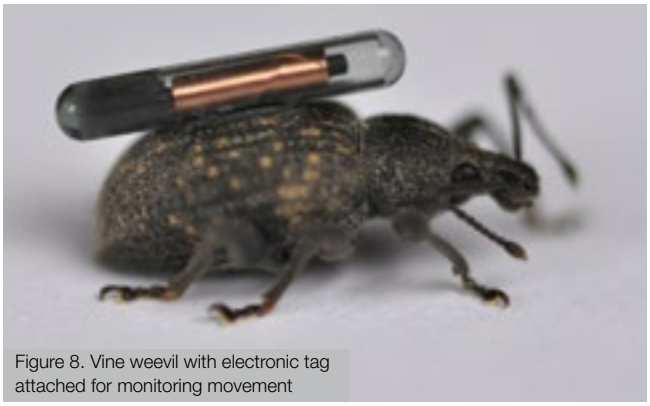

Figure 8. Vine weevil with electronic tag attached for monitoring movement

As such, weevils are likely to remain close to the area in which they emerged, unless their habitat is disturbed, or it becomes unsuitable for other reasons such as drought, senescing host plants or the absence of suitable host plants. Under such conditions, adults are capable of moving over 50m in the search for new crops.

Monitoring techniques

Adult weevils become active soon after dusk and search for suitable host plants to feed on. To monitor for the presence or population level of adults:

- Go onto the nursery at night with a powerful torch and look for them on shoot tips. As vine weevil adults are very sensitive to movement, but not light, they will rapidly drop off the plant and 'play dead' if disturbed. If plants are therefore gently shaken, the adult weevils will fall and can then be easily seen on light coloured surfaces such as sand beds or white material placed under the plants. Vine weevil adults will also aggregate together, particularly in narrow gaps and ridges, such as those found beneath or around the rims of containers and trays.
- Use a length of grooved board, a piece of corrugated plastic or cardboard placed under or near to container-grown stock to create refuges. The weevils may congregate under these refuges and can be found by inspecting them regularly during the daytime. Alternatively, take two plant containers of the same size, fill both with straw and secure the open end of the containers together using some tape. Place them on their side within the crop. The adult weevils will then enter the containers through the drainage holes in the bases of them and aggregate together in the straw.

- However, AHDB Horticulture-funded project HNS 195 has found that a commercially made vine weevil trap is a more effective monitoring tool than grooved boards or corrugated materials. This simple trap is made of black plastic and is shaped to allow weevils to enter the trap but not leave. Although the trap is commercially made it is not yet currently available in the UK.
- Create pitfall traps placed close to a suspected infestation, however bear in mind such traps will also catch beneficial insects such as ground beetles. To create a pitfall trap bury a plastic cup in the ground up to its lip, and coat the upper inside edge with grease to stop the adult weevils crawling out. To prevent the trap from filling with irrigation water or rain, invert a three-litre container (with its drainage holes covered with tape) over the pitfall and cut three legs into the rim, so the weevils can crawl underneath it into the trap.

The most visible sign of infestation is the feeding by adult weevils that causes notching along leaf margins (Figure 3). This damage may reduce the value of the plant or even render it unsaleable. It is not always easy to spot this damage as it may be hidden or only present on a few leaves. Notches are also harder to detect on plants with irregular leaf margins or needles, such as *Spiraea* or *Taxus*. Always look for notching on new growth, as old leaves from the previous year may still show old feeding damage.

Use of trap plants as monitoring aids

Plant genera that are very attractive to weevils, such as *Euonymus* or *Primula*, can be used as indicators of both adult feeding and egg laying:

- Place undamaged indicator plants in areas where attack from adult vine weevil is expected, and inspect these plants regularly for notches along leaf margins. Remove any notched leaves once recorded so new notching can be easily seen. Control measures against adults can be timed accordingly.
- Place a layer of sharp sand on the top of the growing medium in the container, to help in detecting the start of egg laying. The sand can be removed at weekly intervals and the eggs, if present, can be floated off in a saturated salt solution. Once any debris has been removed by sieving, it is possible to see the eggs clearly. Growers may not have the time to undertake this monitoring system, but some consultants may offer to do this.

To sample for larvae within the growing media, knock the plants out of the container and examine the root ball. The larvae are sometimes visible on the outside of the root ball, however, it may be necessary to split open the root ball or even split the plant crowns to find all the larvae. Trap plants that are attractive to egg laying and larval development should be managed carefully and disposed of on a regular basis to prevent them from becoming sources of infestation.

Range of crops affected

Vine weevil adults and larvae feed on a very wide range of host genera and species. Results from a grower survey and a review of the available literature on the range of plant species attacked by vine weevil are summarised in AHDB Factsheet 18/10 'Host plant range of vine weevil'. The factsheet includes tables of highly susceptible crops as well as crops that are rarely attacked. Understanding the susceptibility of different crops is important in targeting control measures and monitoring efforts.

Most susceptible plant genera and species are fed on by both adults and larvae but, in some cases, plants are damaged by adults only, such as *Hebe*, or larvae only, such as *Heuchera* or *Sedum*. *Heuchera* may be particularly susceptible as the many fine fibrous roots around the edge of the root ball aid larval survival. Understanding whether a crop is susceptible to both adults and larvae or not is another important consideration when monitoring or selecting control measures.

It is also important to remember that weeds as well as crops can act as vine weevil hosts. The most common weed host species include dandelion, dock and rosebay willow herb.

Influence of growing media on vine weevil numbers

Vine weevil larvae can develop and survive in all types of growing media. However, previous projects funded by both AHDB Horticulture and Defra, examining the efficacy of plant protection products along with the impact of different growing media blends have indicated that more vine weevil larvae may survive in media consisting of coir than peat, bark or peat blended with green compost.

In addition, entomopathogenic nematodes are likely to be more effective in container-grown hardy nursery stock than in field-grown stock due to the medium being more evenly and better irrigated, while some soils are less favourable for nematode movement.

Control

Traditionally, vine weevil control was achieved via the use of persistent insecticides incorporated into the growing media. Although there are still some insecticide products approved for use in this way, growers are now under increasing retail and government pressures to reduce their reliance on chemical control measures. The Sustainable Use Directive (SUD) requires that in EU member states, integrated pest management (IPM) should be used by all professional users of plant protection products, as long as practical and effective methods are available. Current IPM methods for control of vine weevil include cultural and biological control methods together with monitoring and the selective use of chemical plant protection products, when necessary. Flow charts summarising the various actions that can be taken to control the pest from early to late season are presented in Figures 9a and 9b (located in the wallet at the back of the factsheet).

Cultural control

Vine weevil thrives on plants that have been kept on the nursery for more than one season, in old stock plants and in neglected areas. Paying close attention to nursery hygiene can help to reduce sources, not only of vine weevil but also of other pests and diseases:

- Carefully and promptly dispose of unsaleable plants and growing media badly infested with vine weevil larvae by sending them to landfill.

- Keep weeds in or around glasshouses, polythene tunnels and production beds under control, particularly those that can potentially harbour vine weevil, such as dandelion, dock, knotweeds, plantain and rosebay willow herb.
- Remove plant debris between crops to reduce the number of refuge sites for adult vine weevils.
- Check a sample of bought-in plants for adult weevil leaf notching and for the presence of larvae by knocking them out and searching through the growing media.
- Ask the supplier of the plugs or liners what control measures have been used for vine weevil management.

Biological control

Commercial biological control agents available for vine weevil management include one based on an entomopathogenic fungus and several based on various entomopathogenic nematode species.

Entomopathogenic fungus

Currently, there is only one entomopathogenic fungus species approved for vine weevil control in the UK, *Metarhizium anisopliae* (now renamed *M. brunneum*), sold as Met52 Granular Bioinsecticide. This product is a granular product formulated on rice grains that has the characteristic green colour of the *Metarhizium* spores. Met52 can be bought pre-mixed into growing media by the growing media supplier or as the product for incorporation into growing media or soil both under protection and outdoors. During mixing, fungal spores break off the rice grains and become distributed through the growing media. When vine weevil larvae come into contact with the spores, the spores germinate on their cuticles and the fungus grows inside their bodies and kills them. Young infected larvae decay rapidly after death but older infected larvae can be found in the growing media and can be recognised by the fungal growth on their bodies, which is white at first but then turns greyish-green (Figure 10). Met52-treated growing media can also be used as a mulch (Table 1, located in the wallet at the back of the factsheet).

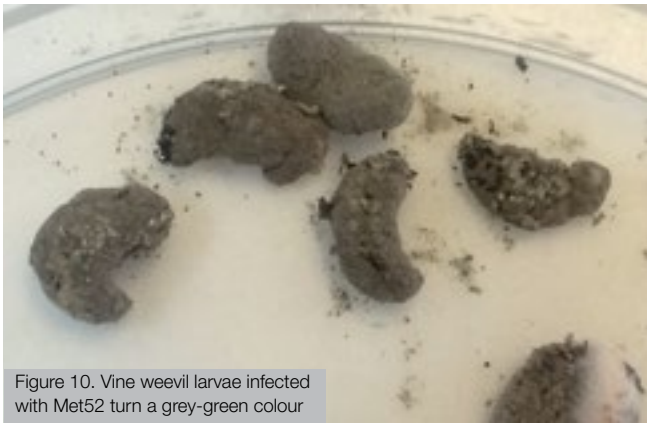

Figure 10. Vine weevil larvae infected with Met52 turn a grey-green colour

Environmental requirements

- Met52 is recommended to be used at temperatures between 15°C and 30°C. Below 15°C the fungus works more slowly and it does not work below 10°C, although the spores will remain viable. The spores do not survive well at temperatures above 40°C.
- Treated growing media should be stored in a shady place, away from direct sunlight and at temperatures below 30°C.
- Met52 can be used in all types of growing media but use in heavy soil types will reduce efficacy.
- The growing media or soil should not be too wet or too dry during and following treatment.

Application methods, timing and persistence

- Met52 should be used in growing media throughout the production cycle from plugs to final potting. When potting on into larger containers, the fresh growing media should also be treated.
- The product should be thoroughly incorporated into growing media using the recommended rate and using clean mixing equipment, free from plant protection product residues. Once mixed, the growing media should be used within 30 days.
- When applied to the soil before planting in the spring, it should be incorporated into the top 5cm. Met52 should not be applied to soil before autumn planting.
- Met52 can also be applied as a mulch around established ornamentals for the control of vine weevil larvae and the ground-dwelling life stages of certain other pests such as leatherjackets, midges, sciarid flies and thrips (Table 1).
- The product should be applied before vine weevil egg laying occurs, not as a curative treatment. In container-grown crops, it is likely to be more effective when used during spring potting rather than in the autumn.
- Met52 is likely to persist in treated growing media or soil for a year, but will only infect vine weevil larvae under favourable conditions. For example, the product will stop working when temperatures become too cool in the autumn, but it will become active again once temperatures rise in the spring. Therefore, larvae could become infected with spores in the autumn, but they will not die until the following spring, by which time plant damage may already have occurred and the presence of live larvae in containers could cause crop rejection at the point of sale.
- The effect of typical fluctuating temperatures on Met52 efficacy is not well understood. This is being investigated in the current AHDB Horticulture-funded project HNS 195.

Monitoring for Met52 efficacy

- Check for live and dead vine weevil larvae in the growing media from April to September and look for symptoms of Met52 infection (Figure 10).
- The presence of Met52 in treated growing media can be checked for by using fresh mealworms in a simple test. Guidelines are available from Fargro.
- Suppliers of treated growing media can keep reference samples to check for the presence of Met52, if required.

Use within an IPM programme

- Met52 should not be relied upon as the sole method for vine weevil control, but should be used as part of an IPM programme for vine weevil management.

- Monitor regularly for live vine weevil larvae, particularly when growing media temperatures drop below 15°C in the autumn and apply a curative drench of nematodes as required, selecting the nematode species and product according to the prevailing temperatures.
- In addition, monitor for vine weevil larvae that may have burrowed into the fleshy crowns of some herbaceous subjects such as *Bergenia*, *Heuchera*, *Saxifrage* and *Sedum* as these larvae will be protected from Met52 spores in the growing medium. Apply a curative drench of nematodes or a plant protection product, if required (Table 1).
- As Met52 is a fungus, it could be adversely affected by some fungicides applied as drenches to the growing media. Check the supplier's recommendations. Further work on the side effects of fungicides on Met52 is being undertaken in the current AHDB Horticulture-funded project HNS 195.
- Met52 could have some adverse effects on ground-dwelling life stages of biological control agents. Check with the supplier for details.

Entomopathogenic nematodes

Commercially available entomopathogenic nematode products contain microscopic worms (infective third stage juvenile nematodes, Figure 11) in an inert carrier. When received, the nematodes are in a semi-desiccated state but they quickly hydrate and revive when water is added. Once applied to moist growing media, the infective juveniles swim to find vine weevil larvae or pupae, homing in on carbon dioxide or exudates released by weevil-damaged roots.

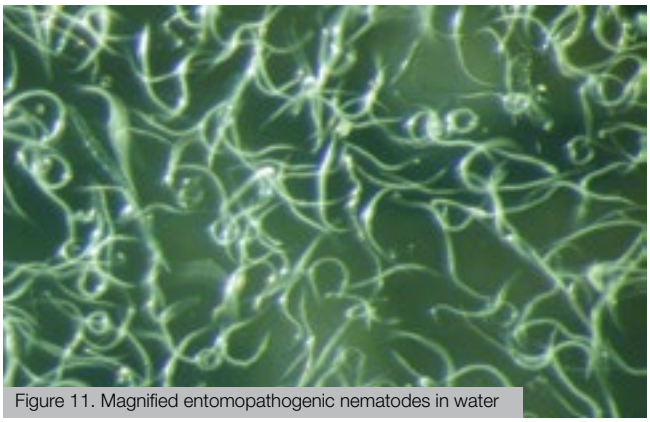

Figure 11. Magnified entomopathogenic nematodes in water

The juveniles then enter the host's body through natural openings such as the mouth or anus. *Heterorhabditis* species can also penetrate the host insect cuticle using a tooth. Once inside the body, the nematodes release symbiotic bacteria that they carry in their gut. *Steinernema* nematode species carry *Xenorhabdus* species of bacteria and *Heterorhabditis* species carry *Photorhabdus* species. These bacteria then multiply within the vine weevil and kill it by septicaemia within a few days. The multiplying bacteria provide suitable conditions inside the vine weevil body for the nematodes to grow into adults and reproduce. This leads to a new generation of infective juveniles that leave the disintegrated vine weevil cadaver to find more vine weevil larvae or pupae to infect.

Nematode species and products

In the UK, commercially available nematode products contain either *Steinernema kraussei*, *Heterorhabditis bacteriophora* or a mix of three species: *Steinernema carpocapsae*, *S. feltiae* and either *H. bacteriophora* or *H. megidis* (Table 2, located in the wallet at the back of the factsheet). The latter species mix is marketed for the control of a range of insect species in one application, for example vine weevil larvae, leatherjackets and sciarid fly larvae. *Steinernema kraussei* products are useful for spring and late autumn applications as this nematode species is effective at soil or growing media temperatures down to 5°C. All nematode species are effective at temperatures up to 30°C (Table 2).

Vine weevil larvae infected with *Heterorhabditis* species turn a red colour (Figure 12) whereas those infected with *Steinernema* species turn a less noticeable yellow-brown colour. However, infected larvae killed by both nematode species disintegrate very quickly after death. Using numbers of live vine weevil larvae remaining a few weeks after treatment is, therefore, a more reliable guide to the level of control achieved than counting infected larvae.

Figure 12. Vine weevil larva infected with *Heterorhabditis bacteriophora* turns a red colour

Application timing and frequency

Nematodes should be applied for curative control when larvae are present in the growing media, they will also control weevil pupae. As eggs can be laid over a protracted period, from April (from overwintered adults) or from June (new adults) through to October or potentially November under protection, larvae could be present at any time of year (Figure 7).

There are two windows of opportunity during the year for nematode application. The most commonly used timing is in late August to October when most eggs will have been laid and larvae of various ages will be present, while growing media temperatures are still suitable for the nematodes to work. It is a good idea to order nematodes for this application timing in advance to ensure an adequate supply. The nematodes only persist in the growing media in sufficient numbers to kill larvae for four weeks after application (as long as conditions are suitable). A second autumn application is, therefore, recommended by some suppliers two to four weeks after the first (depending on the timing of the first application and the growing media temperatures), to control larvae hatching from later-laid eggs.

The other 'window' for nematode application is during April and May to control overwintered larvae and pupae, but timing is critical to target applications when growing media temperatures are warm enough, but before adults emerge from pupae.

Current research in AHDB Horticulture-funded project HNS 195 is evaluating a 'little and often' approach for the application of nematodes each month between May/June and October using overhead irrigation systems to apply the nematodes. This method is already used by some growers in commercial crops of strawberry, applied through drip irrigation.

Application process

It is essential to follow all the supplier's recommendations carefully for optimum control of vine weevil larvae using nematodes.

Storage before use

- As soon as received, store the product in a fridge at the temperature recommended by the supplier (2–6°C, 5°C or 4–10°C, depending upon the supplier and product).
- Do not freeze the product.
- Use the product by the expiry date printed on the pack.

Application conditions

- Apply when growing media or soil temperatures are within the optimum range for the species being used (Table 2) for at least several hours a day and for at least two to four weeks (depending upon product recommendations) after application.
- Apply to moist growing media or soil, if necessary irrigate before application.
- Apply in the early morning, late afternoon or evening to avoid the harmful effects of high temperatures and UV light. There is no need to mix the nematodes in the dark but, ideally, this should be done away from bright sunlight.

Nematode application rates

- Use the rate of nematodes recommended by the supplier. The rate is given as numbers per m^2 for soil or calculated per m^2 for pot-thick containers. Some suppliers also give details of how many containers of different sizes can be treated by each pack.
- One supplier (e-nema) recommends a rate per m^2 for use in open soil and a rate per litre for use in growing media.
- Usually, the recommended rate for use in soil is higher than that recommended for use in containers.
- One supplier (Koppert) recommends two rates, one for small-scale infestations and a higher rate for large-scale infestations.
- One supplier (e-nema) recommends increasing (doubling) the rate if the growing medium contains green compost or perlite.
- Use the whole pack(s), do not divide them between applications as the nematodes may be unevenly distributed within the pack.

Water application volumes

- Once the nematodes have been mixed with water at the recommended rate, apply them in the recommended volume of water per m^2. This water volume is specified by some suppliers but not others. Some suppliers give recommended volumes of water per container depending upon container volume.
- After application, irrigate with water to wash any nematodes off the foliage into the growing medium. The volume of water to use is specified by some suppliers but not others.
- As a rule of thumb for application to containers, the total amount of water applied (including that used for nematode application and that used for irrigation afterwards) should be approximately 10% of the container volume, but this will depend on the media moisture content prior to application. For example, for a two-litre container, a total of 200ml of water should be applied. Higher water volumes are sometimes used (such as one-third of the container volume), to ensure that the nematodes reach the vine weevil larvae. Care should be taken when using higher water volumes to ensure that the drench does not run out of the bottom of the container.

Using spray application equipment

- All equipment, regardless of application method, should be cleaned prior to nematode application, particularly if it has been previously used for a plant protection product or fertiliser application. A few plant protection products can have a deleterious effect on nematodes, check with the supplier for further details. Do not tank mix with plant protection products or fertilisers, unless specifically recommended to do so by the supplier.
- Remove all fine filters in the spray lines and nozzles, 0.3mm or smaller, in order to prevent them filtering out the nematodes from the spray solution. If the size of filters is unknown, they are best removed.
- Use nozzles with apertures of at least 0.5mm or 0.8mm diameter (depending upon supplier recommendations) and apply as a medium/coarse spray.
- Do not use high pump pressures – over 5, 12 or 20 bar (depending upon supplier recommendations).
- Empty the whole pack(s) of nematodes into a bucket, rinse the packs out with a small amount of water and then add 5–10 litres of water (depending upon product recommendations) and stir well.
- Partially fill the sprayer tank with water (at a temperature of 5–15°C or 15–20°C, depending upon the product and supplier).
- Start the agitator and add the nematode suspension to the tank through the sieve. Rinse the bucket well and add the rinsings to the tank.
- Keep the agitator running and add the remaining required amount of water to the tank. Apply immediately for best results and do not leave the nematode suspension longer than four hours before use.
- Keep the nematode suspension agitated throughout the application procedure in order to prevent the nematodes settling out.
- Irrigate immediately after application to wash the nematodes off the foliage into the growing media, this also helps to disperse the nematodes. When irrigating, take care not to cause run-off from the tops of containers.

Using calibrated irrigation equipment

- Calibrated irrigation equipment can also be used with an accurate dosing unit (such as a water powered proportional dosing unit, Figure 13).
- Set the injection rate on the dosing injection unit to the appropriate dilution rate (normally 1% is suitable for nematode application).
- Calculate the area to be treated, the number of nematode packs required based on the recommended nematode rate and the water volume required in the concentrate bucket or feeder tank, based on the recommended water volume.
- Mix the concentrated suspension of nematodes with one to three litres of water in the concentrate bucket or feeder tank to rehydrate the nematodes and mix thoroughly to ensure that the nematodes are well dispersed. Add the remaining volume of water required for the area to be treated. If the solution is too viscous, add an additional known volume of water and adjust the injection rate accordingly.
- Place the dosing unit feeder pipe into the concentrate bucket or feeder tank (Figure 13).
- Keep the nematode suspension in the concentrate bucket or feeder tank agitated constantly, following mixing and throughout application. This can be achieved by hand stirring, using a mechanical propeller set at low revs or using an aquarium air pump.
- Apply in the correct volume of water per unit area.
- After application, rinse the concentrate bucket or feeder tank and inject through the system.
- Allow sufficient time for the nematode solution to pass through the irrigation system, both at the start and end of the application process.

Figure 13. Water powered proportional dosing units can be used to apply nematodes

Using drip irrigation equipment

- Although application of nematodes using drip irrigation is more commonly used in soft fruit production, some hardy nursery stock growers plumb a dosing unit into the drip irrigation system and apply the solution to container-grown trees and specimen plants.
- Check with the supplier that the drip irrigation system to be used is suitable for nematode application.
- Use a dye to test how long it takes the water to reach all the plants before nematode application and to check that all drippers are working and are not blocked.
- Calculate the nematode dose rate using dripper output and container size and calculate how long the nematode suspension needs to be applied for.
- A suitable dosing unit should be used and the nematode suspension agitated prior to and during injection into the irrigation lines.
- Delivery of nematodes through replicate drippers can be checked by collecting the suspension into small containers. The help of the supplier or a consultant may be needed in order to do this.
- Treating individual blocks at a time will give a more uniform application than treating several blocks at a time.
- Consider spot treatments with a spray applicator at the ends of the drip lines as fewer nematodes are applied here due to the water 'bouncing' back at the end of the lines.
- Consider applying nematodes in the first drip irrigation of the day to avoid nematodes being left in the irrigation lines. Otherwise, flush the lines out with water after application.

Monitoring to check nematode efficacy

Check a few plant containers before application with nematodes and record how many live vine weevil larvae are present in the growing media. Mark the containers and check them again after two weeks (as long as growing media temperatures are within the recommended range) and record how many are dead or have changed colour to red (if treated with *Heterorhabditis* species, Figure 12) or yellow-brown (if treated with *Steinernema* species). Check again after a further one to two weeks and record numbers of live larvae remaining.

Nematodes for the control of adult vine weevils

Although nematodes are only applied by commercial growers for the control of vine weevil larvae and pupae, they can also control adult vine weevils. E-nema markets a vine weevil trap in Germany for the home-garden market, Nematop® Käfer-Stopp (Weevil-Stop), and these traps are now available in the UK for amateur use. The trap is a small piece of wooden board with grooves on the underside that are filled with a gel containing high numbers of *Steinernema carpocapsae*. The dampened trap is placed on the soil, growing media or ground. Adult weevils that take refuge under the traps during the day are killed by the nematodes. In joint-funded project CP 089, an experiment was done to test the efficacy of the traps and speed of kill. Half the released weevils were killed by *S. carpocapsae* within 16 days and 92% were killed within 30 days. The weevils were dissected to confirm nematode infection (Figure 14). The traps are currently too expensive for commercial use, but use of the traps together

with a vine weevil attractant is being investigated in the current AHDB Horticulture-funded project HNS 195. It is possible that this approach may lead to the development of a cost-effective commercial strategy for using nematodes for the control of adult vine weevils.

Figure 14. Dead adult vine weevil crushed to reveal nematodes inside the body, acquired from taking refuge in a Nematop® Käfer-Stopp (Weevil-Stop) trap

Natural predators

Naturally occurring predatory carabid (ground) beetles and staphylinid (rove) beetles commonly occur in hardy nursery stock standing-out areas, as demonstrated in Defra-funded research. In AHDB Horticulture-funded project SF 15b, gut analysis using an antibody technique confirmed that both groups of beetles had predated vine weevil eggs, larvae or adults in strawberry and blackcurrant plantations. Other invertebrate natural enemies of vine weevil include ants, earwigs and both predatory and parasitic wasps. Avoiding the use of broad-spectrum plant protection products will help these natural enemy populations to survive and contribute to vine weevil control.

Shrews, hedgehogs and various birds will also predate vine weevils. Wild birds can be encouraged by local hedgerow management, and natural and artificial refuges can be provided for hedgehogs.

Commercially available beetles

Defra-funded research (project PS2130) demonstrated that the commercially available rove beetle, *Atheta coriaria* (now renamed *Dalotia coriaria*) that is used for the control of sciarid and shore fly eggs and larvae will also predate young vine weevil larvae. Subsequent research at Harper Adams University showed that *Dalotia coriaria* will also eat newly laid vine weevil eggs and that they are compatible with Met52 over a 30-day period. Further research would be needed to investigate the potential of *Dalotia* against vine weevil before it could be recommended.

Chemical control

As stated previously in this factsheet, due to the requirements of the Sustainable Use Directive and to other restrictions on the use of chemical plant protection products, integrated pest management (IPM) programmes with minimal use of such products, should ideally be adopted. Currently approved plant protection products that will give some control of vine weevil are presented in Table 1. These include products incorporated into the growing media or applied as a drench for the control of larvae and foliar sprays for the control of adults.

Application methods

Growing media incorporation for the control of larvae

Thorough incorporation of the granules during the final mixing stages using suitable machinery to ensure even distribution is essential. Follow the application guidelines on the product labels and in supplier technical leaflets.

Drenches for the control of larvae

As a rule of thumb for application to containers, the volume of water applied in a drench should be approximately 10% of the container volume, but this will depend on media moisture content prior to application. For example, for a two-litre container, a total of 200ml of water should be applied. Higher water volumes are sometimes used (for example one-third of the container volume), to ensure that the drench reaches all the growing media in the container, but care should be taken when using higher water volumes that the drench does not run out of the bottom of the container.

Foliar sprays for the control of adults

Foliar application(s) should be considered against adult weevils in April and May (overwintered adults) or June and July (new adults) if monitoring indicates activity. Ideally, these will help to control adults before they commence laying eggs. Select a plant protection product with the least negative effects on the biological control agents used against other pests. Research in AHDB Horticulture-funded project SF/HNS 112 showed that pymetrozine (Chess WG) gave promising control of vine weevil adults and this product is more compatible with biological control agents than broad-spectrum insecticides (Table 1). Research in the current AHDB Horticulture-funded project HNS 195 is investigating both the lethal and sub-lethal effects (including reduced fitness or egg laying) of IPM-compatible insecticides on adult weevils and the optimum time of day for application.

When applying foliar sprays, good coverage is required, including leaf undersides; this is particularly important for contact-acting products. Appropriate nozzle types, pressures and spray volumes should be used in order to achieve the necessary spray coverage; nozzle selection and the pressure used will affect the droplet size and spray volume applied. A medium or fine spray is appropriate for pest control in ornamental crop production. Good spray penetration is less likely to be achieved on closely spaced plants with a dense foliage canopy. Spray coverage can be checked using water-sensitive paper to detect the density and uniformity of spray deposits within a crop.

Integrating plant protection products with biological control agents in an IPM programme

Within an IPM programme, products safest to biological control agents used against other pests should be used. Further details of the side effects of plant protection products on biological control agents can be found on the following websites: **biobest.be** and **koppert.com**. If necessary, seek the advice of an IPM consultant, the biological control supplier or the supplier of the product. A summary of the various components of vine weevil IPM programmes for container-grown ornamentals can be found in Table 3 (located in the wallet at the back of the factsheet).

Further information

AHDB Horticulture factsheets and publications

Factsheet 06/15: 'Improving the efficacy of plant protection applications to ornamental crops via hand-held sprayers'.

Factsheet 18/10: 'Host plant range of vine weevil'.

Factsheet 10/07: 'Guidelines on nursery hygiene for outdoor and protected ornamental crops'.

AHDB Horticulture grower summaries and reports

HNS 195: 'Improving vine weevil control in hardy nursery stock'.

HNS 15c: 'Hardy Nursery Stock: Efficacy and persistence of suSCon Green against vine weevil in different growing media'.

SF/HNS 112: 'Evaluation of insecticides and insecticide mixtures for control of adult vine weevil'.

SF 15b: 'Predation of vine weevil in soft fruit plantations'.

CP 124: 'Managing ornamental plants sustainably (MOPS) – Developing integrated plant protection strategies'.

CP 111: 'A review of vine weevil knowledge in order to design best-practice IPM protocols suitable for implementation in UK horticulture'.

CP 089: 'Maintaining the expertise for developing and communicating practical integrated pest management (IPM) solutions for horticulture'. (Jointly funded by AHDB, EMT and HTA).

Other publications

A Practical IPM Guide to Controlling Vine Weevil on Ornamental Nurseries. Available from Fargro or via their website, fargro.co.uk/publications/technical.asp

Defra-funded projects PS2140 and PS2134: 'Use of refuge traps to disseminate entomopathogenic fungi for the control of adult vine weevil'.

Defra-funded project PS2130: 'Potential control of wheat bulb fly, slugs and vine weevil using the predatory beetle *Atheta coriaria*.

Horticulture LINK project HLO171: 'Development of the fungus *Metarhizium anisopliae* for control of vine weevil and thrips in horticultural growing media'.

Want to know more?

If you want more information about AHDB Horticulture, or are interested in joining our associate scheme, you can contact us in the following ways...

horticulture.ahdb.org.uk

AHDB Horticulture, Stoneleigh Park, Kenilworth, Warwickshire CV8 2TL

T: 024 7669 2051 E: hort.info@ahdb.org.uk

@AHDB_Hort

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Early season: January to April

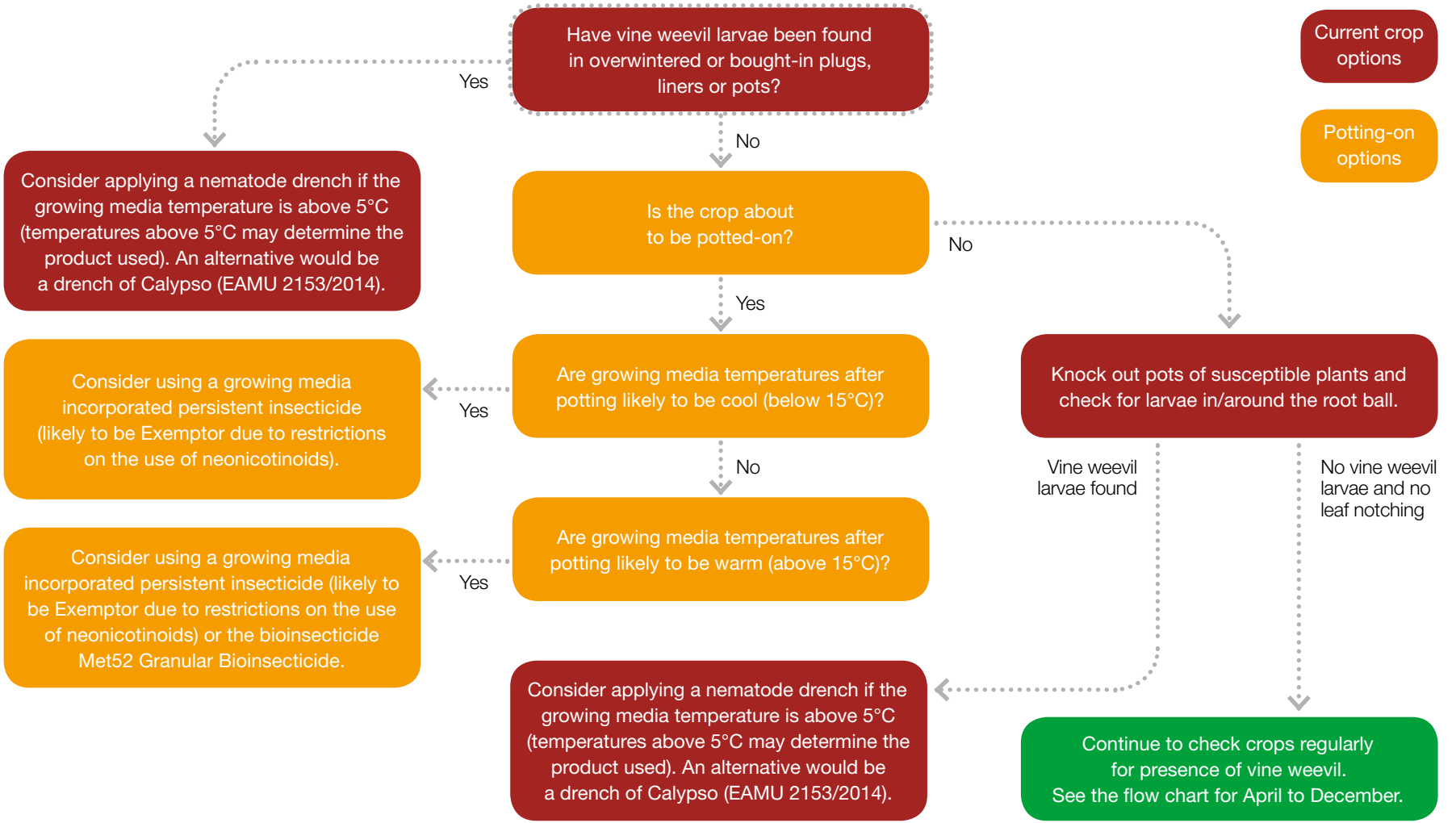
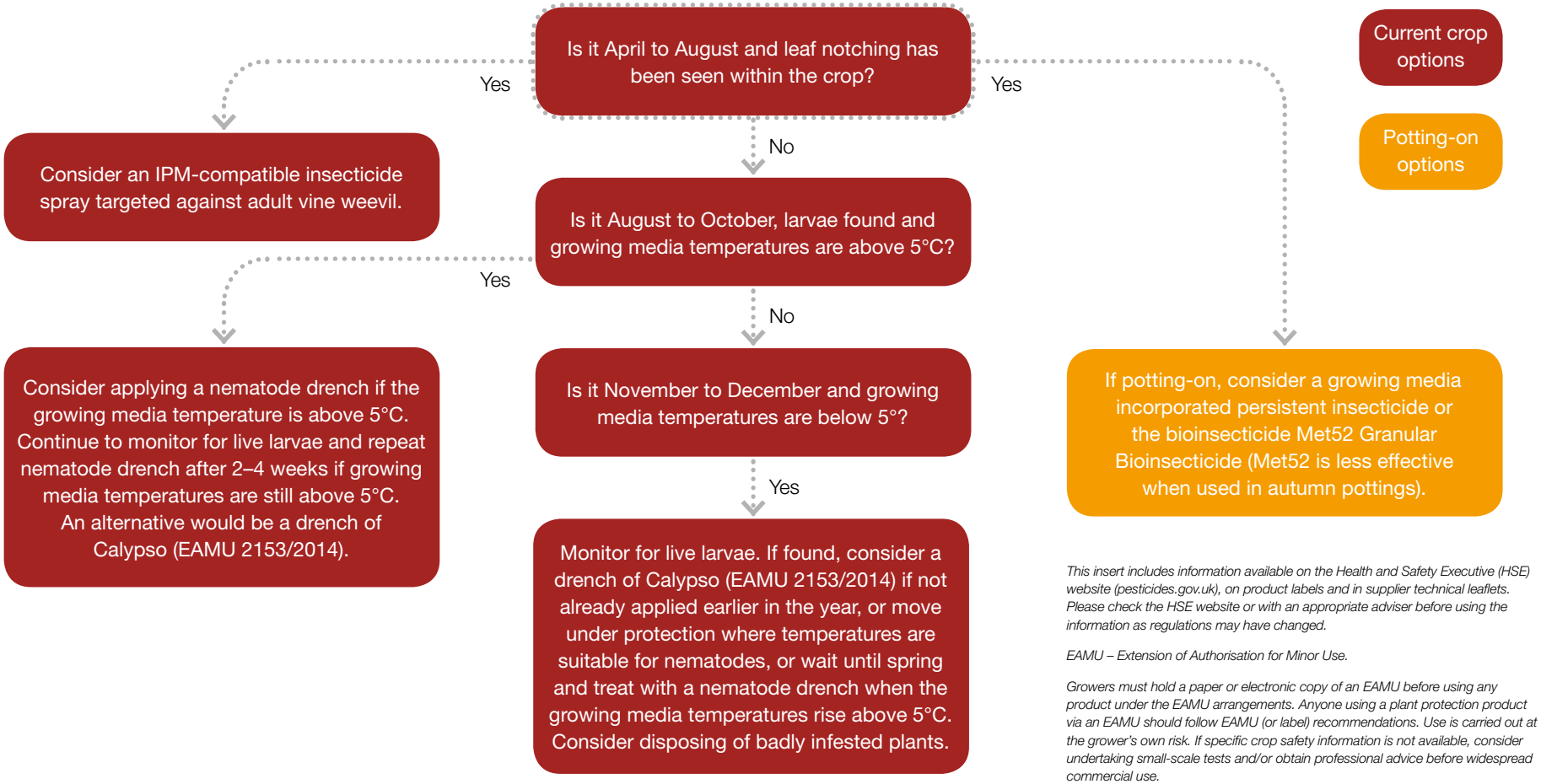


Figure 9a. Decisions in vine weevil management with susceptible container-grown ornamentals

Mid to late season: April to December



This insert includes information available on the Health and Safety Executive (HSE) website (pesticides.gov.uk), on product labels and in supplier technical leaflets. Please check the HSE website or with an appropriate adviser before using the information as regulations may have changed.

EAMU – Extension of Authorisation for Minor Use.

Growers must hold a paper or electronic copy of an EAMU before using any product under the EAMU arrangements. Anyone using a plant protection product via an EAMU should follow EAMU (or label) recommendations. Use is carried out at the grower's own risk. If specific crop safety information is not available, consider undertaking small-scale tests and/or obtain professional advice before widespread commercial use.

If in doubt about which products are permissible, or how to use them correctly, seek advice from a BASIS-qualified consultant.

Details of compatibility of plant protection products with biological control agents are available from biological control suppliers or IPM consultants.

Figure 9b. Decisions in vine weevil management with susceptible container-grown ornamentals

Table 1. Currently approved plant protection products that are either recommended for vine weevil control or will give some incidental control when used for the control of other pests in ornamental plant production (February 2017)

Product name (examples)	Active ingredient and IRAC code	Insecticide group	Approval status for ornamental plant production	Application method	Compatibility with biological control agents used against other pests*	Comments
Biopesticides for the control of vine weevil larvae (incorporation/mulch application)						
Met52 Granular Bioinsecticide	*Metarhizium anisopliae* (now renamed *M. brunneum*)	Entomopathogenic fungus	On-label	Growing media or soil incorporation	Safe to entomopathogenic nematodes. May reduce survival of other biological controls with a ground-dwelling life stage eg *Aphidoletes, Dalotia* (*Atheta*)	Needs 15–30°C when vine weevil larvae present
Met52 Granular Bioinsecticide	*Metarhizium anisopliae* (now renamed *M. brunneum*)	Entomopathogenic fungus	EAMU (1997/2011)	Mulch around established ornamental plant production	Safe to entomopathogenic nematodes. May reduce survival of other biological controls with a ground-dwelling life stage eg *Aphidoletes, Dalotia* (*Atheta*)	Needs 15–30°C when vine weevil larvae present
Insecticides for the control of vine weevil larvae (incorporation/drench application)						
Exemptor	Thiacloprid (IRAC code 4A)	Neonicotinoid	On-label and EAMU (0555/2017) for use in peat-reduced and peat-free growing media	Growing media incorporation	Safe to entomopathogenic nematodes. Label states that side effects on biological control agents not fully established	For use in container-grown ornamentals. Gives up to 17 or 38 weeks' control of vine weevil depending upon dose rate used. Do not use more than two neonicotinoids per crop per year. Not subject to the EC neonicotinoid restrictions**
Imidasect 5GR	Imidacloprid (IRAC code 4A)	Neonicotinoid	On-label	Growing media incorporation	Safe to entomopathogenic nematodes. Label states that side effects on biological control agents not fully established. However, information on use of imidacloprid as a drench indicates harmful to *Hypoaspis/Stratiolaelaps*, slightly harmful to *Phytoseiulus*, safe to *Aphidius*, *Aphidoletes*, *Encarsia* and *Neoseiulus cucumeris*	Can be used in any growing media for use in container-grown ornamentals. Gives up to 12 months' control of vine weevil. Do not use in growing media that has been treated with another imidacloprid product within 12 months. Subject to EC neonicotinoid restrictions**
Calypso	Thiacloprid (IRAC code 4A)	Neonicotinoid	EAMU (2153/2014)	Drench to growing media	Safe to entomopathogenic nematodes. Harmful to *Aphidoletes*, moderately harmful to *Encarsia* and *Neoseiulus cucumeris*, slightly harmful to *Aphidius* and *Hypoaspis/Stratiolaelaps*	Do not use more than two neonicotinoids per crop per year and only one growing media treatment. Not subject to the EC neonicotinoid restrictions**

Table 1. Currently approved plant protection products that are either recommended for vine weevil control or will give some incidental control when used for the control of other pests in ornamental plant production (February 2017) *continued*

Product name (examples)	Active ingredient and IRAC code	Insecticide group	Approval status for ornamental plant production	Application method	Compatibility with biological control agents used against other pests*	Comments
Insecticides recommended for the control of other pests that may give some control of vine weevil adults (spray application)						
Calypso	Thiacloprid (IRAC code 4A)	Neonicotinoid	EAMU (2148/2014) for outdoor ornamentals and EAMU (2151/2014) for protected ornamentals	Foliar spray	Harmful to *Aphidoletes*, moderately harmful to *Aphidius*, *Encarsia*, *Neoseiulus cucumeris* and *Phytoseiulus*	Do not use more than two neonicotinoids per crop. Not subject to the EC neonicotinoid restrictions**
Chess WG	Pymetrozine (IRAC code 9B)	Azomethine	On-label for control of aphids. EAMU (2016/2013) for control of aphids and whiteflies in protected ornamental plant production	Foliar spray	Moderately harmful to *Aphidoletes*, slightly harmful to *Aphidius* and *Phytoseiulus*, safe to *Encarsia* and *Neoseiulus cucumeris*	Research in SF/HNS 112 demonstrated some kill of adult vine weevils
Decis	Deltamethrin (IRAC code 3)	Pyrethroid	On-label for control of other pests	Foliar spray	Harmful to most biological control agents for up to 12 weeks, incompatible with IPM	Research in SF/HNS 112 indicated that some vine weevil populations may be resistant to pyrethroids
Hallmark	Lambda-cyhalothrin (IRAC code 3)	Pyrethroid	On-label for control of other pests	Foliar spray	Harmful to most biological control agents for up to 12 weeks, incompatible with IPM	Research in SF/HNS 112 indicated that some vine weevil populations may be resistant to pyrethroids
Pyrethrum 5 EC, Spruzit	Pyrethrins (IRAC code 3)	Pyrethrins	On-label for control of other pests	Foliar spray	Harmful to most foliar dwelling biological control agents, but short persistence	Research in SF/HNS 112 indicated that some vine weevil populations may be resistant to pyrethroids and therefore could also be resistant to pyrethrins

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If in doubt about which products are permissible, or how to use them correctly, seek advice from a BASIS-qualified consultant.

**Details of compatibility of plant protection products with biological control agents are available from biological control suppliers or IPM consultants. See the following websites: biobest.be and koppert.com. 'Safe': kills<25% of the biological control agents; 'slightly harmful': kills 25–50%; 'moderately harmful': kills 50–75%; 'harmful': kills >75%.*

***With effect from 1 December 2013, professional use of three neonicotinoid insecticides (clothianidin, imidacloprid and thiamethoxam) is no longer permitted on crops considered attractive to bees. Imidacloprid products can only be used on ornamental plants in a glasshouse (not a polythene tunnel) and plants treated with imidacloprid cannot be placed outside until after they have finished flowering. Plants that do not flower can be moved outside following treatment in a glasshouse. Acetamiprid and thiacloprid are also neonicotinoid insecticides but are not currently restricted under these regulations.*

Table 2. Currently available nematode species and products for vine weevil control and growing media temperature ranges (February 2017)

Nematode species	Product name	Producer/supplier	Temperature range
Heterorhabditis bacteriophora	Exhibitline h	Bioline AgroSciences Ltd	12–30°C
H. bacteriophora	Larvanem	Koppert	14–33°C
H. bacteriophora	Nemasys H	BASF	12–30°C
H. bacteriophora	Nematop	e-nema	Above 12°C for several hours per day
Steinernema feltiae	Entonem	Koppert	8–33°C
Steinernema kraussei	Exhibitline sk	Bioline AgroSciences Ltd	5–30°C
S. kraussei	Kraussei-System	Biobest	5–30°C
S. kraussei	Nemasys L	BASF	5–30°C
A mix of *Steinernema carpocapsae*, *S. feltiae* and either *H. bacteriophora* or *H. megidis*	SuperNemos	Flowering Plants Ltd	Above 10°C

Table 3. A summary of the components of a vine weevil integrated pest management programme for container-grown ornamental crops

IPM component	Action
Monitoring	Check around the roots for larvae during March to November, check again two to four weeks after nematode application to guide repeat applications Check for adult activity and damage April to October
Cultural control	Dispose of badly infested plants and growing media, keep weeds under control and maintain good levels of nursery hygiene
Met52 Granular Bioinsecticide	Consider incorporation into growing media for plants potted in the spring/summer. Minimum temperature required for activity against larvae is 15°C Product unlikely to be effective in autumn-potted plants against larvae hatching September to November from late-laid eggs
Entomopathogenic nematodes – timing	Apply as a drench in April if live overwintered larvae are found, repeat in August to October to control larvae hatching from summer and autumn-laid eggs, if temperatures are suitable (two applications may be needed)
Entomopathogenic nematodes – temperatures	*Steinernema feltiae* (Entonem): 8–33°C *Steinernema kraussei* (Exhibitline sk, Kraussei-System, Nemasys L): 5–30°C *Heterorhabditis bacteriophora* (Exhibitline h, Nemasys H): 12–30°C *H. bacteriophora* (Larvanem): 14–33°C *H. bacteriophor*a (Nematop): minimum 12°C Mix of *Steinernema carpocapsae*, *S. feltiae* and either *H. bacteriophora* or *H. megidis* (SuperNemos): minimum 10°C
Chemical control – larvae	Consider thiacloprid (Exemptor) incorporation into growing media. Imidacloprid (Imidasect 5GR) can also be incorporated into growing media, but may only be used with crops grown in glasshouses (not polythene tunnels) and treated plants must not be moved outside until after flowering. An alternative would be a drench of Calypso (EAMU 2153/2014)
Chemical control – adults	Consider foliar spray(s) against adults during April and May (overwintered adults) or June and July (new adults). Chess WG (EAMU 2834/2008 for protected ornamentals) is more IPM-compatible than other pesticides and showed promise in AHDB Horticulture-funded project SF/HNS 112 (The lower, on-label rate has not been tested, but this work is planned in the current AHDB Horticulture-funded project HNS 195)

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