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Recording the movement of adult vine weevil within strawberry crops using radio frequency identification tags

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Abstract.
BACKGROUND: Vine weevil *(Otiorhynchus sulcatus)* is a major pest of soft fruit and ornamental crops. There is an urgent need to improve control of vine weevil and in particular to provide growers with effective Integrated Pest Management-compatible controls with which to target the adult stage of this pest. One approach would be to exploit the behaviour of adult vine weevil to disseminate spores of an entomopathogenic fungus placed within the crop environment in artificial refuges. To be effective this approach requires that the weevils move through the crop environment and in doing so spread the pathogen from the artificial refuges.
OBJECTIVE: Use passive radio frequency identification (RFID) tags to study the movement of adult vine weevil within crop environments.
METHOD: A series of laboratory bioassays were completed in which the effect of attaching RFID tags using a thermoplastic or a cyanoacrylate adhesive on survival and movement, on both horizontal and vertical surfaces, of adult vine weevil was determined. An outdoor field experiment was then completed at Harper Adams University in order to test the potential of this technique for studying vine weevil movement within crop environments.
RESULTS: Attaching RFID tags using the thermoplastic adhesive did not result in any weevil deaths over a 21 day period. In contrast, just over half (53%) of the weevils to which the RFID tag was attached using the cyanoacrylate adhesive died over the same period. The mean of weevil horizontal movement speed was significantly slower when an RFID tag was attached using a thermoplastic (1.01 cm/s) or a cyanoacrylate (0.29 cm/s) adhesive compared with untagged weevils (1.83 cm/s). However, weevils that were tagged using the thermoplastic adhesive were significantly faster than weevils tagged using the cyanoacrylate adhesive. Mean vertical movement speed was also significantly slower when weevils were tagged using the thermoplastic adhesive (0.18 cm/s) compared with untagged weevils (0.37 cm/s). Weevils tagged using the cyanoacrylate adhesive were unable to climb vertical surfaces.

In the field experiment, weevils moved away from their release points. Nine days after the start of the experiment weevils were on average 3.38 m from their release points indicating a speed of movement of 0.38 m/day. The mean distance of movement from their release points did not increase further during the rest of the experimental period, but remained relatively constant at between 2.50 and 3.28 m. As such, for weevils that remained within the crop environment, there is no evidence of dispersal behaviour,

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with movement behaviour observed more likely to be driven by resource utilisation. However, not all weevils remained within the crop area. Indeed, 15 (38%) of released weevils and/or RFID tags left the crop area, indicating possible long range dispersal by these individuals or evidence of predation of the weevils.

A total of 11 (28%) of the RFID tagged weevils released into the crop were recovered alive and with the tag still attached after 35 days. These weevils were estimated to have moved a distances of between 2.65 and 17.30 m (average distance moved 7.50 m) during this period. These distances are likely to underestimate the distance moved by each weevil as they assume that each weevil took the most direct route between each point and did not move other than this. In total eight of the RFID-tagged weevils moved both along and between rows of strawberry grow-bags. At the start of the experiment the 11 RFID tagged weevils occupied 11 (14%) of the strawberry grow-bags. If these weevils took the most direct route between each position within the crop where they were detected these weevils would have crossed, and potentially laid eggs in, 44 (58%) of the grow-bags during the 35 days of the experiment. If they had taken a more indirect route the weevils could have potentially laid eggs in a higher number of the grow-bags.

CONCLUSIONS: Results presented here indicate that RFID tags can be used to study the movement of vine weevil adults within crop environments. However, the weight and size of currently available tags significantly slows the movement of weevils under laboratory conditions and frequency of detection may affect estimates of actual distance moved. Despite this, the rate at which vine weevil dispersed through the strawberry crop was comparable to the speed of movement recorded previously by others when weevils were released into an urban environment. Use of RFID tags also resulted in detection rates far higher than those reported in studies by others using traditional mark-release-recapture techniques. Use of RFID tags in the present study indicates that adult vine weevil have the potential to disperse spores of a suitable entomopathogenic fungus from artificial refuges throughout the crop environment. Use of this technique could also be applied to investigate the effect of other plant protection products as well as the impact of different cropping systems on vine weevil movement and survival.

Keywords: *Otiorhynchus sulcatus*, RFID, remote sensing, tracking, movement, mark-release-recapture

1. Introduction

Vine weevil *(Otiorhynchus sulcatus)* remains one of the most serious pests of soft fruit and ornamental crops [17]. Damage is caused both by the adults, which feed on leaves, and larvae, which feed on plant roots, corms and tubers. As the larvae are root pests and the adult weevils are nocturnal an infestation may pass unnoticed for some time until leaf notching is noticed or plants show signs of wilting, by which time they will have been damaged beyond recovery.

Growers are currently able to use Integrated Pest Management (IPM) compatible options to control vine weevil larvae, such as entomopathogenic nematodes and the entomopathogenic fungus *Metarhizium brunneum (anisopliae)* [1, 13, 21]. In contrast, growers are currently reliant on the use of broad spectrum insecticides for the control of vine weevil adults. However, using insecticide applications targeted against adult vine weevil is difficult, as it is generally believed that they need to be applied at dusk, when the weevils become active. In addition, these insecticide applications themselves have a negative impact on biocontrol agents used against other pests and on naturally occurring beneficial insects, such as ground beetles that predate on vine weevil adults [8]. Furthermore, recent research has shown that the insecticide lambda-cyhalothrin, which is widely used to control adult vine weevil, may give inconsistent levels of control [6].

There is thus an urgent need to develop effective IPM-compatible options for control of vine weevil adults. One approach currently under investigation seeks to exploit vine weevil behaviour to achieve control of this pest through the use of an entomopathogenic fungus [19]. The approach is based on the fact that adult weevils are nocturnal and seek refuge during the day, show aggregation behaviour and, like the larval stages, are susceptible to infection by entomopathogenic fungi [17]. Given these features of vine weevil biology it may be possible to use the vine weevils themselves to disseminate entomopathogenic fungi throughout the crop. Known as auto-dissemination [9–11], this approach would use artificial refuges to first establish foci of infection within the crop. Vine weevil using these refuges would become contaminated with infective fungal conidia before returning to the crop, where they could potentially serve to disseminate the pathogen throughout the pest population.

In order for this approach to be effective weevils must readily use artificial refuges and then move through the crop environment in order to spread the entomopathogenic fungus from the artificial refuges. However, there is little information on the movement of adult vine weevil within crop environments. This is partly due to the difficulty in using traditional mark-release-recapture studies. In a recent study, 894 and 2,753 adult vine weevils were marked and released into a raspberry crop, but recapture rates were just 2% and 12%, respectively [7]. This study did not record the distance moved by each weevil, however, in an earlier study [14] a mark-release-recapture technique was used to record dispersal of adult vine weevils in an urban environment. In this study weevils were recaptured 21, 35 or 57 days after release. During this time the weevils had travelled mean distances of 6.8, 17.2 and 31.2 m, respectively, although most weevils were recovered less than 10 m from the release site. Again recapture rates in this study were low. Of the 2,323 weevils marked and released only 5.7% were recaptured.

Recent technological advances in animal tracking techniques may overcome the limitations of traditional mark-release-recapture studies of species such as vine weevil through remote sensing of the insect [12]. The most common methods of remote sensing of insects are harmonic radar and radio frequency identification (RFID). Both of these systems use a passive tag (without a battery), which helps to minimise the weight and size of the tag. The harmonic radar tracking system uses a radar to transmit a specific harmonic frequency and to detect a second different harmonic frequency, which is returned from the tag (a harmonic transponder) fitted to the insect [24]. Harmonic radar has been successfully used to study a wide range of insects, including an attempt to study vine weevil [5]. However, harmonic radar has not yet been used to explore the spatial behaviour of vine weevil nor has the impact of the tag on weevil walking activity or survival been investigated. RFID uses radio frequency magnetic fields to transfer data, typically a unique identification number, without contact between the tag and the reader [23]. As each tag has a unique identification number it is possible to discriminate between tags, unlike harmonic radar. RFID has been used to study the spatial behaviour of a range of insects including the banana weevil *Cosmopolites sordidus* [25].

This paper presents results from a study in which RFID tags were used to track the movement of adult vine weevil in a strawberry crop to inform development of an auto-dissemination technique with which to control this pest.

2. Materials and methods

2.1. Insects

Weevils used in the RFID tagging experiments were collected from commercial strawberry crops grown in Shropshire and Staffordshire. Before use weevils were kept in small groups (25–30 individuals) in ventilated plastic containers placed in a controlled environment chamber set to 20°C, 60% relative humidity and a 16 : 8 h photocycle. Each container was lined with tissue paper, had a source of moisture (damp tissue paper), refuge (corrugated cardboard) and food source (strawberry leaves).

2.2. RFID tagging

RFID equipment used in the study was supplied by Biomark® (Boise, Idaho, USA). The tags used were HPT8 (8.4 mm 134.2 kHz FDXB) and these were read using an HRP Plus reader fitted with an HRP Plus antenna. Results from preliminary work found the maximum read-range of this combination of tag and reader was approximately 14 cm. This read-range was unaffected by growing media or grow-bag plastic placed between the tag and the antenna. In the experiments presented here the tag was attached to a weevil by first restraining the weevil by gently pressing it onto a softened roll of putty (Blue tack®, Bostik Ltd, Leicestershire, UK). Next a small droplet of adhesive was applied to the elytra of the weevil. Two types of adhesive were examined; a thermoplastic adhesive applied using a hot glue gun (TEC250LT, Basildon, Essex, UK) and a cyanoacrylate gel (Power Easy Gel, Loctite, Hertfordshire, UK). For both types of adhesive, a tag was gently pushed onto the elytra of the weevil immediately after applying the adhesive. Once the adhesive had set and the tag was securely fastened the weevil was removed from the putty. Each tag weighs approximately 30 mg excluding the weight of the adhesive used to affix the tag to the weevil.

2.3. Weevil survival experiment

A weevil survival bioassay was completed using 45 vine weevils. Thirty of the weevils were selected at random and a tag was attached following the method previously described. Fifteen of the tags were attached using the thermoplastic adhesive and another fifteen were attached using the cyanoacrylate gel. The remaining 15 weevils were left untagged and provided a control. Each weevil was maintained individually in a ventilated Petri dish placed in a controlled environment chamber set to 18°C and 65% relative humidity. Weevils were fed pieces of *Primula* leaf and provided with pieces of damp tissue paper for moisture at regular intervals. Weevil survival was recorded over a 21-day period.

2.4. Weevil movement experiment

Movement bioassays were completed using adult vine weevils carrying RFID tags attached using the thermoplastic adhesive or the cyanoacrylate adhesive as previously described. Untagged weevils were used as the control in this experiment. As in the weevil survival bioassay each adhesive was used to attach RFID tags to 15 weevils while a further 15 weevils were left untagged. The movement of each weevil was recorded before the tag had been attached and 24 hours after tag attachment. To record weevil movement on a flat (horizontal) surface, weevils were placed in the centre of a well-lit arena, the base of which was covered with plain white paper. Each weevil was placed directly underneath a bright light held 10 cm above the sheet of white paper in order to trigger movement away from the centre of the arena. The time taken for an individual to cover a distance of 10 cm was recorded. To record weevil movement on a vertical surface (similar to the side of a plastic plant pot), weevils were placed inside a transparent plastic tube with a 3 cm diameter. The tube was placed in a vertical position and the time taken for the weevil to climb to a height of 10 cm was recorded. For both the horizontal and vertical bioassays each weevil was recorded over three replicated runs and the mean of these taken.

2.5. RFID field experiment

A ‘commercial’ strawberry crop was established at Harper Adams University, Shropshire. Strawberry plants (cv. Elsanta) were grown in one metre grow-bags, 10 plants in each bag. A total of 76 grow-bags were arranged in four rows of 19 on a woven geotextile ground-cover membrane. The crop was grown outdoors. The distance between each row was one metre (measured from the centre of each row). Weevil movement within the strawberry crop was recorded during July and August 2013. Temperature and rainfall data were collected during the same period. The thermoplastic adhesive was used to attach RFID tags to a total of 40 weevils using the method previously described. The tagged weevils were released during the day into the strawberry crop on 3 July. Each weevil was released after first scanning the attached tag to record the unique identification number before placing the weevil in the centre of a strawberry grow-bag. Alternate bags in each row were infested with a single weevil in this way. Twenty-four hours after releasing the weevils, the position of each weevil within the strawberry crop was determined using the HRP Plus reader fitted with an HRP Plus antenna. Each grow-bag was scanned along both sides as well as over the top of the bag. In addition, the area between each row of bags was scanned as well as the area immediately around the strawberry crop (5 m) for the presence of tagged weevils. After recording the position of the tagged weevils on 4 July the position of weevils was subsequently recorded on 5, 6, 7, 8, 10, 12, 16, 20 and 28 July as well as 7 August. On 7 August a detailed search of the strawberry crop was completed and where possible weevils and tags recovered. Where dead weevils with a tag still attached and detached tags were recovered the data collected after the last recorded movement of this tag was excluded from analysis. Movement data was analysed in two ways. Firstly, on each of the 11 assessment dates the distance that each of the detected weevils had moved away from its starting position was recorded. Secondly, the shortest cumulative route taken by each healthy weevil with a tag still attached on 7 August was estimated. To do this the distance between each point within the strawberry crop that the weevil was detected was recorded assuming that the weevil had taken the most direct route between each point. Using this approach it was also possible to estimate the total distance moved and the number of grow-bags visited by each weevil.

2.6. Statistical analysis

Data were analysed by analysis of variance (ANOVA) using Genstat 16th Edition (VSN International Limited).

3. Results and discussion

3.1. Weevil survival experiment

No mortality was recorded for untagged weevils or weevils carrying an RFID tag attached using the thermoplastic adhesive over a 21-day period. However, eight (53%) of the 15 weevils carrying an RFID tag attached using the cyanoacrylate adhesive died during the course of this experiment. Although widely used to attach harmonic radar and RFID tags to insects, cyanoacrylate adhesives have been reported to affect some species of insect, for example Western corn rootworm *(Diabrotica virgifera virgifera)* and Northern corn rootworm *(Diabrotica longicornis)* while other species, such as the plum curculio *(Conotrachelus nenuphar)*, appear to be unaffected [3]. In previous work developing a harmonic radar system to study adult vine weevils [5], attaching the harmonic radar transponder and antenna to vine weevil adults using a cyanoacrylate adhesive was not reported to affect survival. Indeed, anecdotally it was reported that one weevil carried a transponder and antenna for over a month 'without apparent ill effects'. One notable difference between the harmonic radar study and the work presented here is that in the harmonic radar study the dorsal surface of the weevil was wetted with water to act as a catalyst before applying the cyanoacrylate adhesive. The cyanoacrylate adhesive product used in the harmonic radar study is also unknown. More work is, therefore, required to determine if the use of a water catalyst or a different cyanoacrylate adhesive would be more appropriate for attaching RFID tags to vine weevil adults.

Thermoplastic adhesives are less frequently used to attach tags to insects but have previously been used in studies recording the movement of beetles [16, 18]. Thermoplastic adhesives have been found to offer a number of advantages over cyanoacrylate adhesives. The main benefit of thermoplastic adhesives is the speed with which they set [18], meaning that insects only have to be restrained for a short period of time.

3.2. Weevil movement experiment

Mean horizontal speed of movement (Fig. 1) did not differ significantly ($F = 0.56$, P = n.s.) between each group of weevils before RFID tags had been attached (means of 1.44–1.59 cm/s). Attaching RFID tags to weevils significantly ($F = 74.37$, $P < 0.001$) affected horizontal speed of movement. Individual contrasts using least significant difference (LSD) found that the speed of movement of untagged weevils (1.83 cm/s) was significantly faster than weevils tagged using the thermoplastic adhesive (1.01 cm/s). Weevils tagged using the thermoplastic adhesive were in turn significantly faster than weevils tagged using the cyanoacrylate adhesive (0.29 cm/s). Mean vertical speed of movement (Fig. 1) did not differ significantly ($F = 0.25$, P = n.s.) between each group of weevils before RFID tags had been attached (means of 0.45–0.46 cm/s). After attaching the RFID tags using the cyanoacrylate adhesive none of the weevils were able to climb up the walls of the tube. Of the 15 weevils tagged using the thermoplastic adhesive eight were still able to climb the vertical surface. However, speed of movement was significantly ($t = 5.11$, $P < 0.001$) slower (0.18 cm/s) than untagged weevils (0.37 cm/s).

There has been relatively little work to investigate how attaching a tag to an insect may affect the behaviour of the tagged individual [12]. Work that has been completed indicates that the response of walking insects to the additional weight of tags is variable both within and between species. This is because both the weight and the distribution of that additional weight may be important in determining the speed and distance travelled [4].

The weight of the RFID tag used in this study was approximately 30 mg and the weight of an adult vine weevil was approximately 90 mg, meaning that the RFID tag weighed around 30% of the weight of the weevil. The weight of the RFID tag used here is very similar to the weight of the transponder-antenna combination used in the harmonic radar system developed for adult vine weevil [5]. However, as movement assays with the transponder-antenna attached to the weevil were not completed in the harmonic radar study it isn't possible to compare the impact that the two types of tag have on vine weevil behaviour. Reducing the size and weight of the RFID would clearly be an advantage, however, while smaller and lighter tags are available the distance over which they can detected may be as little as 3 mm [23].

The apparent importance of the adhesive used to attach the RFID tag to the weevil appears to reflect the results from the survival experiment (see above). Based on the results of the survival experiment and the movement assays the thermoplastic adhesive was selected for use in the field experiment.

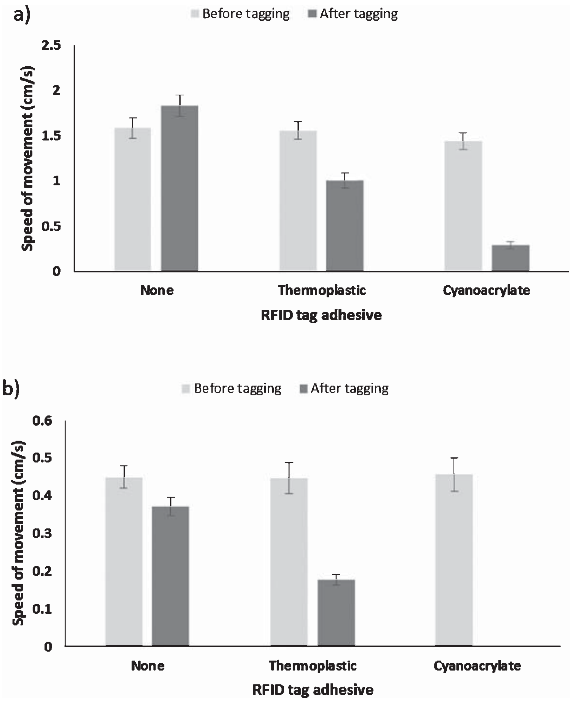

Fig. 1. Vine weevil speed of movement under laboratory conditions on horizontal (a) and vertical (b) surfaces before and after RFID tags have been attached using a thermoplastic or a cyanoacrylate adhesive (mean ± SE).

3.3. RFID field experiment

The positions of RFID tagged weevils were successfully recorded. The numbers of healthy tagged weevils detected on each recording date remained high, compared with recovery rates achieved in previous mark-release recapture studies, throughout the experiment (Fig. 2). The number of healthy tagged weevils detected was highest on the first (one day after release) and second (two days after release) assessments (25 weevils or 63% of the number released). The lowest number of healthy tagged weevils was detected nine and 35 days after release (11 weevils or 28% of the number released). The decline in numbers of weevils detected during the first nine days of the experiment occurred during a period of warm (mean temperatures 14.3°C–21.1°C) dry weather. In the final assessment, completed 35 days after the weevils were released, all tags were collected so that the number of healthy tagged weevils could be confirmed. In total 25 (63%) of the tags were recovered from within the crop area. Eight healthy tagged weevils were found within the crown of the strawberry plant. Three healthy tagged weevils were recovered from within or under a grow-bag. Four other tagged weevils were recovered but had died during the course of the experiment. Ten tags, which had become detached from the weevil, were also recovered. Throughout this experiment, no weevils were found between the rows of strawberry grow-bags or in the area immediately around the crop. Despite this, 15 (38%) of the released weevils had left the crop area, indicating possible long range dispersal. Indeed, it has been a reported that vine weevil are capable of migrating up to 50 m to new strawberry plantations [20]. Nonetheless predation cannot be excluded, particularly birds and mammals [17], which would be likely to carry the tagged weevil away from the crop area.

The numbers of weevils detected on each assessment in this study were much higher than those previously reported using conventional mark-release-recapture techniques [7, 14]. This represents a clear benefit of exploiting RFID technology to record the behaviour of vine weevil over conventional techniques. Indeed, adult vine weevils are an ideal candidate for using RFID technology as these insects are robust, relatively large (8.5 to 11.5 mm in length and 90 mg in weight) and are flightless [22].

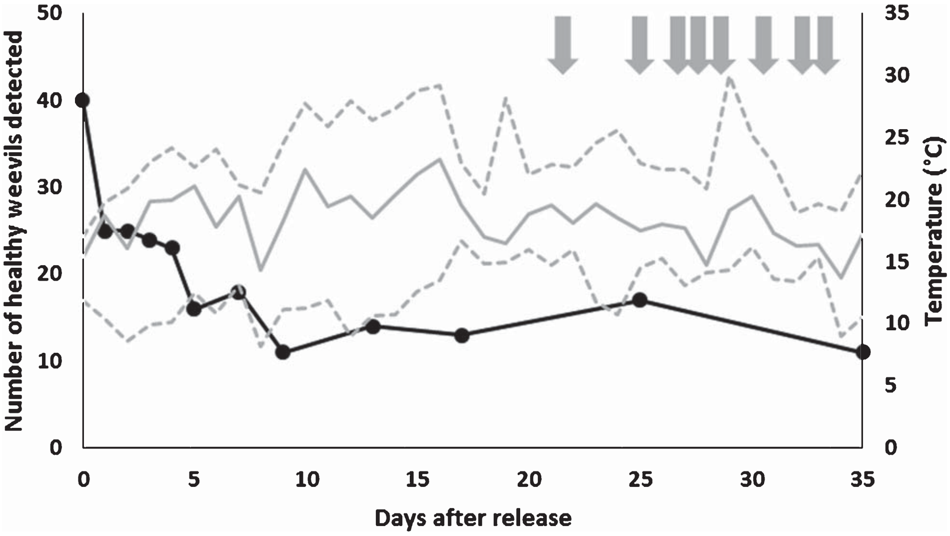

Fig. 2. Number of live RFID tagged vine weevils detected under field conditions on each assessment (data collected after the last recorded movement of a tag that was subsequently found to be detached or attached to a dead weevil is excluded). Mean temperature indicated by solid grey line with maximum and minimum temperatures indicated by dotted grey lines above and below this. Grey arrows indicate a rainfall event of over 1 mm within 24 hours.

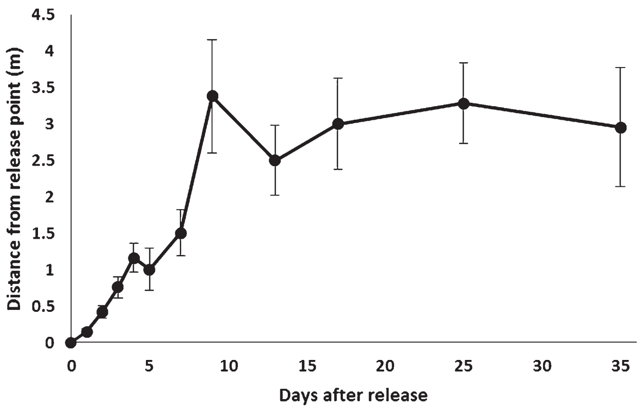

Fig. 3. Vine weevil dispersal under field conditions from release point (mean ± SE).

The mean distance moved by vine weevil from the release point reached 3.38 m nine days after release (0.38 m/day) (Fig. 3). This distance was calculated by simply measuring a straight line between the release point and the detection point. The mean distances from the release points did not increase further during the rest of the experimental period and remained relatively constant between 2.50–3.28 m. Despite this, the distance moved by each weevil varied widely so that nine days after release, weevils had moved as little as 0.33 m (0.04 m/day) from the release point or as much as 7.07 m (0.78 m/day). These results are broadly similar to those reported in a mark-release-recapture study in an urban environment where the distance travelled by weevils from the release point was recorded after 21, 35 or 57 days [14]. In this study the weevils had travelled mean distances of 6.8 (0.32 m/day), 17.2 (0.49 m/day) and 31.2 m (0.55 m/day), respectively. Interestingly, results from the mark-release-recapture study in an urban environment indicate that the speed of movement increased the longer the period between release and recapture. In the present study the mean distance moved by weevils from the release point did not increase after the first nine days. However, weevils that appear to have left the crop area, and were potentially moving greater distances, were not recorded and

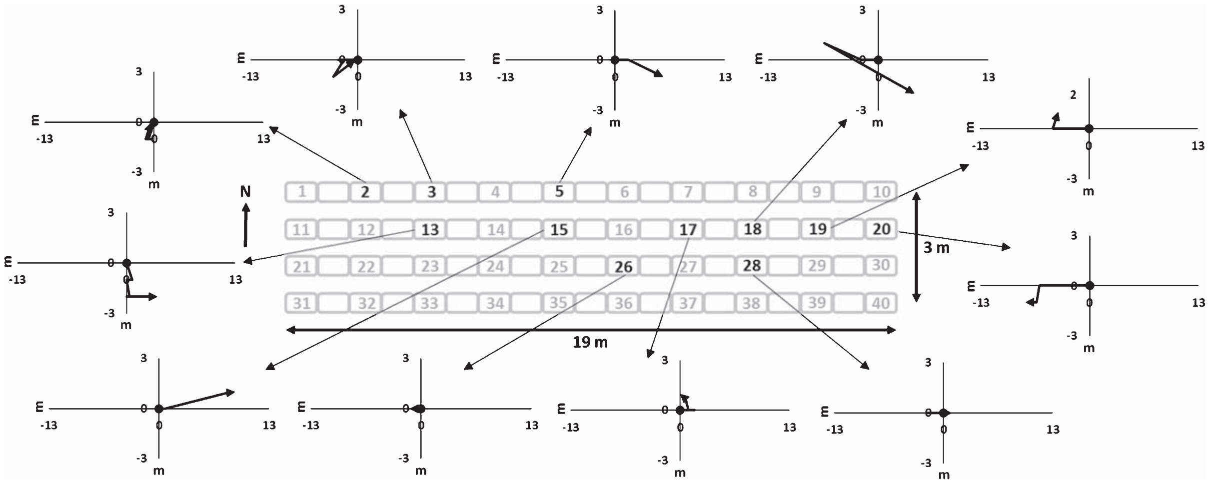

Fig. 4. Plots illustrating movement of 11 RFID tagged vine weevils on four rows each of 19 strawberry grow-bags. Each weevil was recorded as healthy and still tagged after 35 days. Black numbers indicate the approximate start positions of each of the 11 weevils within the crop area and grey numbers indicate the approximate start positions of RFID tagged weevils, which had either died, the tag had become detached or the weevil and/or tag had left the crop area during the experimental period. The arrow in each plot indicates the direction and distance (m) travelled by each weevil relative to the start position.

so the effect that these weevils would have had on recorded mean distances moved and speed of that movement is unknown. Individual plots (Fig. 4) of mean displacement over time showed no evidence of random movement, which is consistent with non-searching behaviour. In the context of remaining within the crop, it can be concluded that movement is directional, but localised. Only 14% of observations indicated that movement direction was reversed (180° turn), which suggests that food availability was not a strong influence on behaviour.

The fact that the distance between the position of each weevil and its release point did not increase throughout the experimental period suggests that weevil movement was driven by resource utilisation rather than dispersal behaviour. This in turn reflects the fact that the released weevils were surrounded by abundant feeding, shelter and oviposition sites within the crop. However, as 15 (38%) of the released weevils left the crop area during the assessment period it remains possible that a proportion of the weevils did indeed show dispersal behaviour or were being predated upon birds or other natural enemies. Given the numbers of weevils released into the crop area it is likely that any such dispersal behaviour was driven more by discovery of new habitats than escape from an overpopulated or deteriorating habitat [2].

Plotting the routes taken by the 11 weevils (Fig. 4), which were tracked throughout the 35 day-period shows that the distance moved per day remained relatively constant throughout the study period. In total these weevils were estimated to have moved between 2.65 and 17.30 m (average distance moved 7.47 m) in the 35 days. These estimates are based on weevils taking the most direct route between each point at which the weevil was detected. As such the positions of the weevils recorded may not take into account additional non-linear night-time movement. In addition, the position of each weevil was not recorded every day, due either to gaps between assessments or weevils not being detected each time an assessment was completed. As such the estimates of distance moved for each weevil are likely to be less than the distances actually moved. In this respect harmonic radar tracking systems may provide more detailed information and is capable of recording a continuous track that the insect took [24]. However, the range of the harmonic radar system previously developed to study the movement of adult vine weevils was modest at 3-4 m and was further reduced when the weevils were on the ground and obscured by a slight depression in the soil or vegetation [5]. As such the harmonic radar system previously developed could not easily be used to allow continuous monitoring of vine weevil movement within crops.

In total eight of the RFID tagged weevils tracked through the 35-day period moved both along and between rows of strawberry grow-bags. At the start of the experiment the 11 RFID tagged weevils occupied 11 (14%) of the strawberry grow-bags. Assuming that these weevils took the most direct route between each point at which they were detected these weevils would have crossed, and potentially laid eggs in, 44 (58%) of the grow-bags during the 35 days of the experiment. If they took a more indirect route, they would have potentially laid eggs in a higher proportion of grow-bags. This result demonstrates how, despite the relatively short distances moved by each weevil, a small number of weevils has the potential to infest a significant proportion of a crop area. In addition, as an adult vine weevil is capable of laying up to 17 eggs per day under optimum conditions [15] each weevil may only have to spend a short period of time on each grow-bag to initiate a severe infestation. Further work is required to investigate how this result relates to different cropping systems, such as table-top grown strawberries, or other soft fruit crops.

4. Conclusions

Use of RFID tags represents a viable alternative to the use of traditional mark-release-recapture techniques to study the movement behaviour of adult vine weevil. The fact that adult vine weevils are relatively large, robust and flightless makes this species an ideal candidate with which to apply this approach. Despite this, results from the laboratory movement assays indicate that the weight and size of currently available tags does significantly slow the movement of weevils. However, under field conditions the speed of movement recorded was comparable to those previously reported for this species. Detection rates using the RFID system were also far higher than those reported in studies using traditional mark-release-recapture techniques. In addition, the use of RFID tags meant that assessments were relatively quick to complete and left the insect undisturbed.

Results from the field experiment indicate that for the weevils that remained within the crop area, movement appears to be driven by resource utilisation rather than dispersal. Despite this, the mean distance moved by tagged weevils remaining in the crop area was 7.47 m in 35 days. This movement was sufficient for tagged weevils to cross, and potentially lay eggs in, an average of four grow-bags each. Although the role of predation cannot be excluded, the fact that 38% of the tagged weevils left the crop area suggests that these individuals did show dispersal behaviour.

Recorded vine weevil movement behaviour also supports the hypothesis that adult vine weevil have the potential to disperse spores of a suitable entomopathogenic fungus from artificial refuges throughout the crop environment. RFID tag data indicate that nine days after release weevils had moved 3.38 m from the release point. Preliminary data indicates that adult vine weevil are killed by suitable entomopathogenic fungi within 7–10 days under optimum conditions for the entomopathogenic fungus (Chandler pers. comm.). However, further work is required to determine what effect, if any, early stages of infection have on vine weevil movement behaviour.

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