The effect of controlling codling moth (*Cydia pomonella*) with *Steinernema carpocapsae* (Nemasys® C) on crop yield

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Abstract

Autumn applications of the entomopathogenic nematode (EPN) Steinernema carpocapsae (Rhabditida:Steinernematidae) as the commercial product Nemasys® C are used by growers on top fruit, especially apples, across Europe. Applications targeting the overwintering pre-pupal stage of the codling moth (Cydia pomonella, Lepidoptera: Tortricidae) reduce the adult population the following spring. Beneficial nematodes as a tool for reducing pest pressure the following season can be used to compliment all of the different pest control programs; mating disruption, virus and chemical insecticide. Applications of EPN are also an important tool in resistance management.

Two commercial scale field trials were carried out in France in autumn 2008. Sentinel larvae in cardboard traps on trees and in the ground along with artificially infested logs were used to assess nematode efficacy. For the first trial at Caumont application of S. carpocapsae (Nemasys® C) resulted in 80, 87 and 80% mortality of sentinel larvae in the soil, on the ground and on the trunks respectively. In the second trial at L'Isle sur Sorgue mortality was 94, 67 and 81% of sentinel larvae in the soil, on the ground and on the trunks respectively.

Two commercial scale field trials were carried out in the UK in autumn 2008. The first trial at Wisbech used an autumn application of S. carpocapsae (Nemasys® C) along with a normal chemical insecticide program the following season. When compared to a chemical only program the addition of the EPN application resulted in a 50% reduction in crop damage the following year. The second trial at Marden used an autumn application of S. carpocapsae (Nemasys® C) along with a mating disruption program the following season. When compared to a mating disruption only program the addition of the EPN application resulted in a 55% reduction in crop damage the following year. Despite the Marden trial being a low yielding site, the reduction in crop damage due to EPN application resulted in an increase of 0.7 t/ha in marketable crop yield. These trials demonstrate the versatility of how autumn applications of S. carpocapsae can be fitted into a variety of pest control programs.

Keywords: *Steinernema carpocapsae*, Nemasys C, Codling moth, *Cydia pomonella*, crop yield

Introduction

Codling moth, *Cydia pomonella* Linnaeus 1785 (Lepidoptera: Torticidae) is a global pest of top fruit. Within Europe it is mostly a pest of apples. There are a number of different methods which have been developed to control this pest. These include chemical insecticides, mating disruption, granulosis virus and most recently entomopathogenic nematodes (EPN). Application of *Steinernema carpocapsae* Weiser 1955 (Nematoda: Steinernematidae) (for example Nemasys® C) to apple orchards has been shown to give high levels of control of overwintering codling moth (Unruh and Lacey, 2001; Cornale *et. al* 2006; Cutro *et. al.,* 2008). The development of EPN such *S. carpocapsae* as a biological

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control agent for codling moth (*C. pomonella*) is being driven by a variety of demands. Chemicals are being withdrawn and there are increasing cases of development of resistance to those chemicals which remain (for example Mota-Sanchez *et. al.,* 2008). There is also more consumer demand for improved levels of environmentally sensitive growing.

Having a pest control product based on a living organism will result in the product having optimum environmental conditions it will require in order to give the best results (Lacey and Unruh, 1998). Understanding of these conditions is an important part in the increasing uptake of biological control products such as *S. carpocapsae* to control codling moth (*C. pomonella*).

Material and Methods

Two field trials carried out in France in autumn 2008. The first at Caumont was carried out in a 4.5 ha apple (var. Royal Gala, planted 1994) orchard. Of the 4.5 ha orchard, 1ha was treated with *S. carpocapsae* (Nemasys® C). Application was made on 16.10.09. *Steinernema carpocapsae* was applied at a rate of 1.5 billion nematodes/ha in 2000 l/ha of water. There was no rain during application so overhead irrigation was used as replacement. Before nematode application 10 mm of irrigation was applied followed by 80 mm afterwards. The second trial was carried out at L'isle sur Sorgue. The total size of the apple (var. Granny smith, planted 1983) orchard was 0.72 ha, of which 0.36 ha was treated with *S. carpocapsae* (Nemasys® C). Applications were made on 20.10.09. *Steinernema carpocapsae* was applied at 1.5 billion nematodes/ha in 1000 l/ha of water. There was no rain during application so overhead irrigation was used. Before nematode application 5 mm of irrigation was applied followed by 23 mm afterwards on the same day followed by 21 m of rainfall the day after application and 22mm of rainfall the second day after application. Efficacy of *S. carpocapsae* application on these two trials in France was assessed with the use of sentinel larvae. Codling moth (*C. pomonella*) larvae had previously been collected from another orchard nearby. They were transferred to corrugated cardboard on wooden strips (2 larvae/trap) or onto pear logs (10 larvae/log). Larvae were allowed one week to hide in the traps before being transferred to the trial orchard. Half of the cardboard traps were placed on the ground surface, the second half were buried 5 cm below the soil surface. The pear logs were tied to the trunks of the trees between the ground and the lowest branch. The same number of traps were placed in the treated block and the untreated control block. Mortality of the sentinel larvae was then recorded 18 days after treatment for the Caumont trial and 14 days after treatment for the L'isle sur Sorgue trial.

Due to lower codling moth (*C. pomonella*) pest pressure experienced in the UK, trials were designed to determine the effect of inclusion of autumn applications of *S. carpocapsae* (Nemasys® C) in either mating disruption or chemical programs on the effect of marketable fruit yield the following year. The first UK trial was carried out at Mudcroft Farm, Cambridgeshire. For the trial at Mudcroft Farm one crop damage assessment the season following nematode application was made. Two fields were used for the trial Q and R. Both fields were very similar with the same apple variety (Bramley) planting date of November 1994, size at approximately 1 ha, and planting density of 4 bed rows. In the previous season the grower had not experienced any difference in levels of crop damage between the two fields, although no data was available. Both fields received the same chemical treatments through 2009. Field R received an autumn application of Nemasys® C after harvest in 2008 field Q received no nematode treatment. *Steinernema carpocapsae* (Nemasys® C) was applied at the label rate of 1.5 billion nematodes/ha in 1500 l/ha of water. Applications were made with the growers orchard sprayer. The crop damage assessment was carried out on 21.07.09 just before harvest. The second UK trial was carried out at Target Farm in Kent. The application at Target Farm was made during rainfall on 15.10.08 using the orchard sprayer. *Steinernema carpocapsae* (Nemasys® C) was applied at a rate of 1.5 billion/ha in 1500 l/ha of water tank mixed with 2.5 l/ha of Codacide (Microcide Ltd., Bury St. Edmonds, UK). Nematode application was made to half of the 8ha apple orchard (var. Bramley, planted 1986). The season following nematode application all of the 8ha field had mating disruption (Exosect Ltd., Winchester, UK) used for control of *C. pomonella*. For the trial at Target Farm crop damage assessments were carried out twice. Early season assessments (15.07.09) and then again later in the year at crop harvest (21.08.09). For sampling fruit damage, assessments for codling moth strike were made on 1000 fruits from each treatment block. Samples of the number of fruits damaged were grouped into 100 fruits, with no more than 25 being taken from the same tree. Sampling from a large number of trees reduced the potential for variation due to natural differences on large plot trials. To avoid potential edge effects trees in the end two rows or first 10 trees in a crop row were not sampled from. Trees with pheromone traps in were also not sampled from.

Temperature and humidity at both of the UK sites was recorded using a EL USB Temperature/RH data logger (Lascar Electronics, Salisbury, UK). No statistical analysis was carried out on either of the field trials carried out in the UK due to there being no repetition on these large scale grower trials.

Results

During application at the first trial in France at Caumont air temperature was 21°C and remained over 14°C for 5 and half hours after application. When assessments on codling moth (*C. pomonella*) were made 18 days after treatment there was an average 82% mortality in the nematode treated block (Figure 1). High levels of mortality were shown in all of the larvae locations tested.

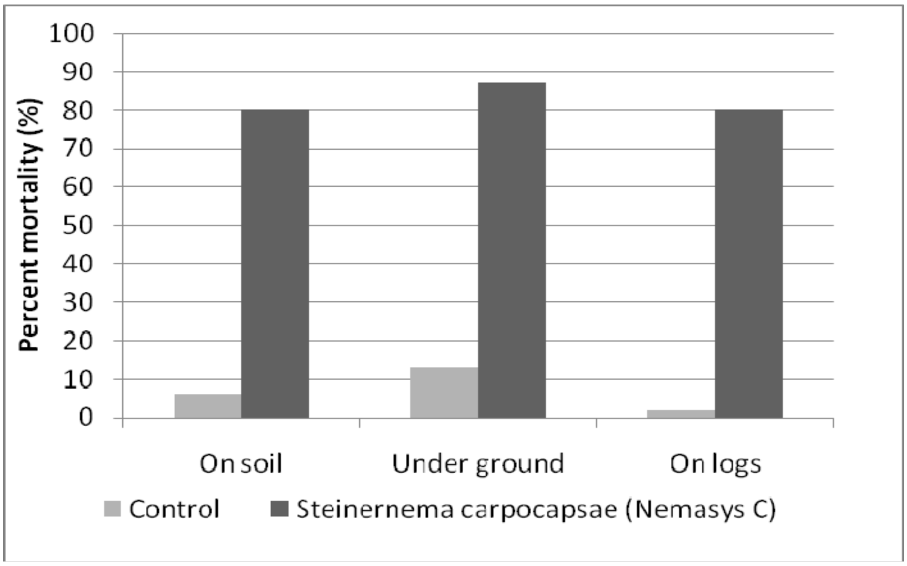

Figure 1: Percent mortality of sentinel codling moth (*Cydia pomonella*) larvae at different locations in an apple (var. Royal Gala) orchard 18 days after application of *Steinernema carpocapsae* (Nemasys® C).

During application at the second trial in France at L'isle sur Sorgue air temperature was 18°C and remained over 14°C for 7 hours after application. When assessments on codling moth (*C. pomonella*) were made 14 days after treatment there was an average 81% mortality in the nematode treated block (Figure 2). High levels of mortality were shown in all of the larvae locations tested.

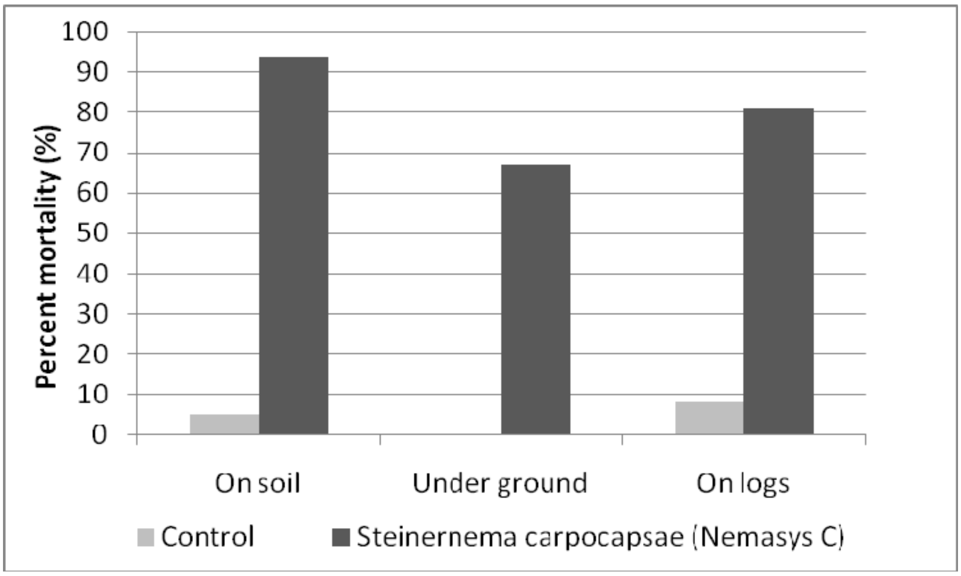

Figure 2: Percent mortality of sentinel codling moth (*Cydia pomonella*) larvae at different locations in an apple (var. Granny Smith) orchard 14 days after application of *Steinernema carpocapsae* (Nemasys® C).

Application of *S. carpocapsae* at Mudcroft Farm was made during rainfall. The season after the nematode treatment both fields received the same chemical treatments. Due to the farm setup there was no distinction in adult activity between fields Q and R. Applications of Runner (a.i. Methoxyfenozide) were made to the crop when pheromone trap catches passed the spray threshold of 5 adults/trap/week. At harvest there was a 50% reduction in the level of crop damage as a result of the nematode application the previous autumn (Figure 3).

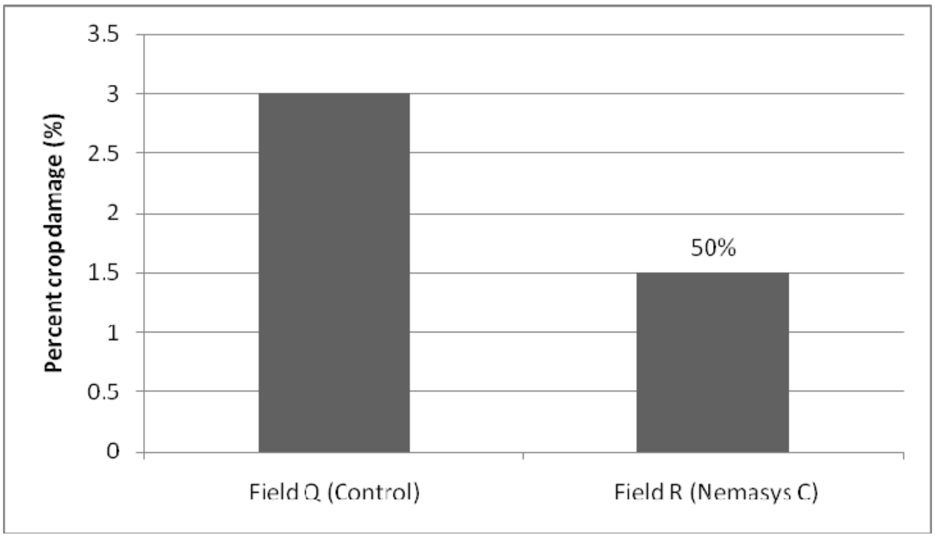

Figure 3: Percent crop damage before harvest to apples (var. Bramley) from codling moth (*Cydia pomonella*) at Mudcroft farm Fields Q and R the season after an autumn application of *Steinernema carpocapsae* (Nemasys® C).

During the trial at Mudcroft Farm, a second pair of fields were also sampled from. In these fields, despite receiving an autumn application of *S. carpocapsae* there were still high levels of codling moth strike. Further investigation showed a relationship between distance from the onsite pack house and the occurrence of crop damage (Figure 4). In the field crop damage was highest in trees next to the pack house (Figure 4, sample point 10). As distance from the pack house increased (decreasing sample point number) the incidence of crop damage decreased.

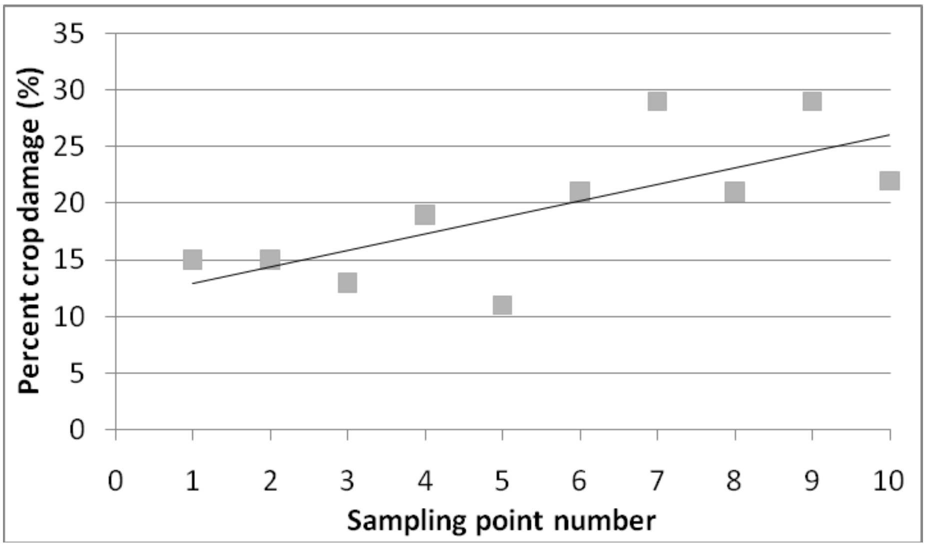

Figure 4: Percent crop damage before harvest to apples (var. Bramley, planted 1984) from codling moth (*Cydia pomonella*) at Mudcroft farm Field H the season after an autumn application of *Steinernema carpocapsae* (Nemasys® C). Sample point 10 is closest to the apple pack house.

Application for the Target Farm trial was made during rainfall. Temperatures during application were 15°C. Average air temperatures remained above 15°C for the 24 hour period following application. Assessments made in mid-July showed the nematode treatment to have resulted in a 54% reduction in crop damage (Figure 5). The assessment carried out later in the year at harvest showed the *S. carpocapsae* treatment to have resulted in a 55% reduction in codling moth damage.

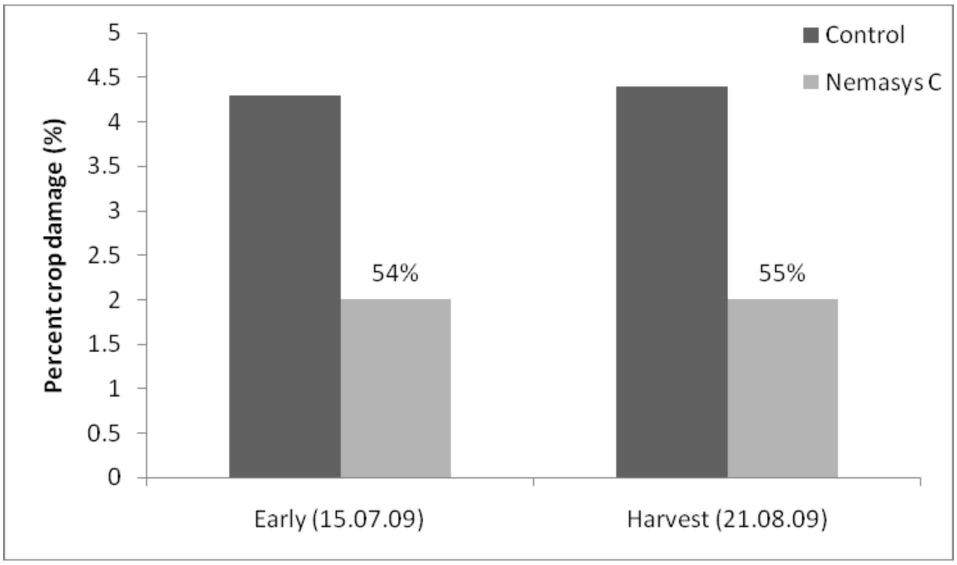

Figure 5: Percent crop damage to apples (var. Bramley) from codling moth (*Cydia pomonella*) at Target farm the season after an autumn application of *Steinernema carpocapsae* (Nemasys® C).

Discussion

The high levels of mortality of over wintering stages of codling moth (*C. pomonella*) in the above trials have demonstrated the ability of the entomopathogenic nematode *S. carpocapsae* to control this important pest. Autumn applications can be used to knock down the population so that there are fewer adults emerging the following spring. A lower pest pressure the following season gives a grower many advantages; lower chemical insecticide inputs as spray threshold will be passed later and less frequently; improved use of mating disruption; resistance management to both virus and chemical as beneficial nematodes are non-selective. It is arguably a change in mindset for many growers to carry out preventative treatments to their crop six months before they will see the benefits. As a result of this, end user education has been an important part in establishment of this product. Further product development and demonstration work is likely to be needed in order to help end user education. It is important that the potential limitations of such commercial products are understood so improved recommendations can be provided making the product as robust as possible. Previous work has shown that application during rainfall is an essential requirement in order to achieve good results. This work has demonstrated that, if applied at a high enough volume, overhead irrigation can be used as a replacement. Where present, overhead irrigation can be used instead of waiting for rainfall, although high volumes of water are required due to the inaccuracies of these irrigation systems. High enough volumes of pre- and post-application water need to be applied in order to fully wet the trees and surrounding soil. Overhead irrigation system are however, not common in European apple orchards and there will still be a reliance on rainfall in order to achieve high level of pest control with *Steinernema carpocapsae*.

Due to low pest pressure from *C. pomonella* experienced in the UK, cardboard traps placed around tree trunks do not work. Instead trial assessments rely upon crop damage the season following nematode applications. This method of assessment gives the benefit of being able to calculate a financial benefit the grower receives as a result of the addition of an autumn treatment with *S. carpocapsae* (Nemasys® C). The two grower trials carried out in the UK demonstrate the ability of *S. carpocapsae* to work on large scale orchards. It also demonstrates the versatility of the product in being able to give benefits to growers using either mating disruption or chemical insecticide programs.

The Target Farm trial showed that Autumn applications of *S. carpocapsae* are able to reduce the level of crop damage the following year if mating disruption is being used. The autumn application resulted in a 54% reduction in damage from the first generation of adult *C. pomonella* and this was maintained throughout the season to harvest. The orchard used in the trial was an old orchard planted in 1986. Trees were planted at only 200 trees/acre, this is significantly lower than newer orchards which can be planted at up to 1000 trees/acre. At this low planting density the field produced 25T/ha of high quality, large apples. The reduced level of crop damage as a result of the autumn nematode treatment resulted in a increase in marketable yield of 0.7T/ha. This figure should be higher in the more intensive modern growing systems. Although adjuvants can be tank mixed with nematode applications to control codling moth such as Codacide used in this trial, it is important that the end users understand that inclusion of an adjuvant, is not an alternative to application of the commercial products in optimum environmental conditions.

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