THE POTENTIAL FOR CONTROLLING THE CABBAGE ROOT FLY [*DELIA RADICUM*] BY RELEASING LABORATORY-REARED PARASITOIDS

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ABSTRACT

The life-cycles of the three parasitoids that attack the immature stages of the cabbage root fly are described together with possible ways of using them in the field. Ways of arresting parasitoids in the vicinity of brassica crops by growing flowering plants as feeding sites, by introducing grassy banks as overwintering refuges and/or by undersowing crops to make the environment more diverse, are discussed. Most of the paper is concerned with the problems inherent in employing parasitoids in the field. These include, how to produce sufficient parasitoids economically and more importantly how to minimize competition not only from other parasitoids but also from the other natural control agents, such as predatory ground beetles. The possibilities for using parasitoids on a large field scale are also discussed.

INTRODUCTION

During the last 75 years, many authors (see Tomlin *et al.*, 1992) have suggested that it might be possible to control field populations of the cabbage root fly (*Delia radicum* L.) using parasitoids. However, no one has yet used parasitoids successfully in this way.

The aim of this review is to determine from the published work which of the methods suggested to date seems most feasible. As I intend this review to be critical rather than encyclopaedic, there are likely to be more questions than answers. Nevertheless, by raising the contentious matters, I hope to identify both a profitable future research programme and those areas where additional research is required.

LIFE-CYCLE OF THE PARASITOIDS

Although five species of Braconidae, three of Eucoilidae and four of Ichneumonidae have been reared from cabbage root fly pupae (for authors see Coaker & Finch, 1971), the eucoilid *Trybliographa rapae* (Westw.) is the only hymenopterous parasitoid of major importance. This insect lays its eggs in all three larval instars of the fly (Wishart & Monteith, 1954) and has been recorded from 60% of the individuals in some samples of overwintering pupae (Wishart *et al.*, 1957). Parasitism of pupae by two beetle species of the genus *Aleochara* is also common. *Aleochara bilineata* (Gyll) is usually more common than *A. bipustulata* (L), possibly because the larvae of *A. bipustulata* find difficulty in entering the puparium of the cabbage root fly, which is thicker than the puparium of its preferred host, the bean seed fly *Delia platura* (Mg.) (Wishart *et al.,* 1957). The two species of *Aleochara* regularly parasitize 20-30% of cabbage root fly pupae (Finch & Collier, 1984) and occasionally 60% (Wishart *et al.*, 1957). The two parasitoid beetles have life-cycles that are out of phase with each other. *A. bipustalata* overwinters as the adult whereas *A. bilineata* overwinters as the first-instar larva within the puparium of its host. Although a few authors have done detailed studies of the life-cycles of the wasp *T. rapae* (Wishart & Monteith, 1954) and the beetle *A. bilineata* (Colhoun, 1953), most references describe the parasitoids merely as mortality factors in the population dynamics of one, or more, pest species of *Delia*. Therefore, a major aim of the future programme will be to do detailed studies of the life-cycles of the parasitoids to determine how the various species interact, particularly under field conditions.

PROPOSED WAYS OF USING PARASITOIDS IN THE FIELD

The work to date has centred on *A. bilineata*, mainly because it prefers cabbage root fly pupae to bean seed fly pupae, and because, unlike the wasp *T. rapae*, it is carnivorous throughout its life-cycle. Hence, researchers believe that *A. bilineata* will act both as a predator and parasitoid providing it enters an infested brassica crop sufficiently early in the life-cycle of the pest. Two ways have been suggested for increasing the impact of the two parasitoid beetles. The first is to release *A. bilineata* inundatively at the time the pest fly starts to oviposit. The beetles would then be active much earlier than normal in brassica crops and could first eat the eggs of the fly, to lower the overall pest infestation, and then lay for their progeny to parasitize the remaining pest insects. The second method proposed is more complex (Ahlstrom-Olsson & Jonasson, 1992) and is based on using the overwintering adults of the beetle *A. bipustulata* to eat the eggs and early-instars of the cabbage root fly larvae, and the second beetle *A. bilineata* to eat the later-instars and also parasitize the pupae. This method involves placing considerable amounts of mustard meal around the base of brassica plants to attract and stimulate females of the saprophagous bean seed fly to lay in the mustard meal. The chemicals associated with bean seed fly larvae feeding within this meal then attract the overwintering adults of *A. bipustulata*, which lay in the meal so that their progeny can parasitize the bean seed fly pupae. As such parasitoid beetles are then at the sites where the later-emerging cabbage root fly lay, it is hoped that the beetle adults will feed on cabbage root fly eggs to mature their own eggs, and in this way lower the overall cabbage root fly infestation. The volatile chemicals associated with the feeding of those cabbage root fly larvae that manage to establish on the brassica plants will then attract first the parasitoid wasp *T. rapae,* and later the second beetle parasitoid, *A. bilineata*.

CONSERVING AND "ENHANCING" THE NUMBERS OF PARASITOIDS IN FIELD CROPS

Under current farming practices, the major impact of naturally-occurring polyphagous predators and parasitoids is to maintain certain soil-pest populations at more or less constant levels from year to year. As insecticides all act in a density-independent manner, large fluctuations in pest populations cannot be tolerated if reduced application rates of insecticide are to remain consistently effective (Suett & Thompson, 1985). Therefore, our principle aim at present is to "conserve" the existing levels of natural pest control. Unfortunately, in most cases, there is little quantitive information on the contribution made to overall pest control by the various biological agents. What is known, is that parasitism can be either high or low in pest populations. What is not known, is whether we can manipulate the field environment to ensure that parasitism is high in all instances. Many researchers within the IOBC Working Group "Integrated Farming Systems" (see Vereijken & Royle, 1989) are now attempting to increase populations of predators and parasitoids by the introduction of additional feeding sites and refuges. The problem with this approach is in assuming that the more beneficial insects there are in the area, the better will be the control of pest species. Pest control may not improve within such systems, particularly if the increase in the numbers of predators/parasitoids reflects merely the increase in the numbers of alternative sources of prey/hosts within the new habitats. Although it might seem like semantics, "increasing" and "enhancing" parasitoid numbers are not synonymous. The word enhance means "to add to the effect". In the field, it is relatively easy to "increase parasitoid numbers" whereas "enhancing their effects" is much more difficult. For example, parasitoid numbers can be "increased" by releasing parasitoids into fly-infested crops. However, if such parasitoids disperse before laying, then obviously they will not "enhance" the levels of pest control locally.

CHANGING THE ENVIRONMENT - ITS EFFECTS ON PARASITOIDS OF THE CABBAGE ROOT FLY

Flowering plants and grassy banks

Improving the general environment for predatory insects and parasitoids is attempted usually by growing flowering plants, in or around monocultures, to provide the beneficial insects with additional sources of food in the form of nectar and/or pollen (Finch,1988). This approach might help to increase the fecundity of *T. rapae*, once the types of flowers visited have been identified. This approach will not directly improve the environment for either species of *Aleochara*, however, as they feed almost entirely on animal protein.

Attempts are being made to introduce refuges, such as grassy banks, into crop fields, to increase the numbers of predators and parasitoids that overwinter successfully (Thomas *et al.*, 1991). This approach will not be effective with *T. rapae* or *A. bilineata* as both overwinter within cultivated fields inside the puparia of their host flies. Refuges might be effective, however, for *A. bipustulata*, particularly if brassica crops are grown after hay (*Lolium perenne L.*), as the plant material left once hay crops have been harvested can support large numbers of bean seed flies and could leave large numbers of *A. bipustulata* overwintering in such fields. The main problem with this approach is that there is no information on whether the refuges increase overall survival or simply alter the distribution of the overwintering beetles.

Undersown crops

The final way to make the environment more diverse within cultivated crops is to undersow the main crop with a forage crop, such as clover (*Trifolium repens* L.). Such systems have an adverse effect on pest insects largely because the pest insects are adapted to plants growing in bare soil (Kostal & Finch, 1994). Unfortunately, the beetle parasitoids of the cabbage root fly are also strongly adapted to bare soil situations and so undersowing with clover reduces the effectiveness of *A. bilineata*, though it appears to improve slightly the levels of parasitization by *T. rapae* (Langer, 1992).

PROBLEMS TO BE CONSIDERED WHEN RELEASING PARASITOIDS OF THE CABBAGE ROOT FLY

Short-season crops

Three factors operate against the use of "classical" biological control in brassica crops: the short growing season of many crops, the transience of the crops due to rotation, and the demand for increasingly high-quality produce. These three factors are complementary as, in the short-term relationship between pest and crop, the natural enemies of the pest have insufficient time to establish their superiority before the crop is damaged and no longer of high quality. This is particularly true for the cabbage root fly, as this fly generally enters brassica crops shortly after they have been transplanted and before the transplants have had time to establish adequate root systems. Therefore, as most brassica crops need to be protected more or less as soon as they are planted, the parasitoids will have to be released shortly after the crop is planted if they are to be effective as predators.

Rearing sufficient parasitoids

The main difficulty in mass-rearing parasitoids of the cabbage root fly is that an artificial diet has not yet been developed and so the host insect still has to be reared on swedes (*Brassica napus* var. *napobrassica*), a method which is both labour-intensive and physically-demanding. There is always the possibility of rearing the parasitoids on the closely-related onion fly (*Delia antiqua*), for which there is an artificial diet (Ticheler *et al.*, 1980) but getting the parasitoids to "switch" back to preferring the cabbage root fly might then become a problem. Perhaps the percentage of beetles that can "switch" from developing on onion fly pupae to developing on cabbage root fly pupae can be maintained at a high level by regularly transferring the insect culture back onto cabbage root fly pupae after having reared them on onion fly pupae for a fixed number of generations? However, it is possible that the beetles may have to be reared solely on the cabbage root fly if this is the species against which they are going to be used in the field.

Cost of parasitoid production

This will depend upon the number of staphylinid beetles required. The only two estimates made at present vary between 20,000 (Bromand,1980) and 650,000 (Hertveldt *et al.*, 1984) beetles per hectare. Using the rearing technique described by Whistlecraft *et al.* (1985), 10 hours of labour would be needed to produce 20,000 *A. bilineata*. Although the work required for this approach might seem daunting, the costs appear to compare favourably with insecticidal control. For example to treat 20,000 plants (1ha) with chlorfenvinphos granules requires 11.2kg of product at a cost of £4.63/kg, or about £52/ha. Therefore, providing the hourly wage, plus overheads, of the workers producing the beetles does not exceed £5, the cost of control using these parasitoid beetles could be similar to that of using insecticide. Application costs might vary, but as chlorfenvinphos granules are applied generally as a subsurface band at a cost of about £30/ha, there appears to be sufficient flexibility to keep within this cost even if the beetles have to be released manually.

Distributing the parasitoids within the crop to be protected

According to Esbjerg & Bromand (1977), *A. bilineata* released into brassica crops disperse at the rate of about 6.5m per day. From studies with beetles marked with radioisotopes, they concluded that for the control of cabbage root fly, batches of several hundred beetles should be placed at each release point, which should be spaced no more than 20m apart to ensure that the beetles spread throughout the crop as quickly as possible. Based on such data, releasing beetles from 16-20 points/ha should not create problems. To be effective, it is likely that the beetles will have to be distributed in this way, as female cabbage root flies are distributed more or less evenly through brassica crops (Finch & Skinner, 1973).

Competition with other parasitoids and with other natural enemies

Although many people believe that an array of parasitoids is preferable to using just one species, when the parasitoids compete for the same resource, the presence of more than one species can prevent the build-up of large parasitoid populations. Reader & Jones (1990) showed that there were marked differences in both the species emerging and in overall mortality when cabbage root fly pupae were attacked by larvae of both the wasp and the beetle. The data of Reader & Jones (1990) were used in an earlier paper (Finch, 1995) to develop a method, based on the timing of when the wasp and beetle larvae entered the host insect, to determine whether the wasp or the beetle survived or whether both perished. To be successful the beetle larvae must enter the fly pupae early in their development. Hence, the competition between the two parasitoids is biased heavily in favour of the wasp, as even if the beetle larva finds a cabbage root fly larva shortly after it has pupated, the beetle larva still needs between 12 and 36 hours to chew its way through the wall of the puparium before it can start feeding on the fly pupa (Colhoun, 1953).

One of the problems of releasing any biological agent into the field is that it has to compete with the established natural enemies. At worst, the release may simply upset the overall local balance so that the existing predators feed in a density-dependent manner on the released parasitoids until the balance is re-established. At such times, it is questionable whether polyphagous predatory beetles can be regarded as "beneficial" insects.

EFFECTS OF CULTURAL PRACTICES ON PARASITOID NUMBERS

Changes in the level of parasitism at a particular site can occur either gradually or rapidly. For example, at one site in Denmark, Bromand (1980) noted a gradual decline from 1971 to 1975 in the numbers of overwintering cabbage root fly pupae parasitized by *A. bilineata*. He associated this decline with a decrease in the area of swedes being grown, which resulted in a larger proportion of the beetles failing to find brassica crops. In contrast, rapid reductions in the levels of parasitism can be caused by some of the soil insecticides applied regularly to control the cabbage root fly (Coaker, 1966: Bromand, 1980), the parasitoids being more susceptible to these insecticides than the host insect (El Titi, 1980;

Finch & Skinner, 1980).

Apart from the adverse effects of pesticides on parasitoids, studies are needed on why ploughing has a greater effect on parasitoids than on pest populations (Finch & Skinner, 1980) and why parasitized pupae are rarely recovered from crops grown in highly-organic soils (Finch, unpublished data).

DISCUSSION

It is clear from this review that trying to enhance the activity of any one parasitoid within a group complex is not easy, as changes to "improve" the environment for one species invariably have the opposite effect on one of the other species. For example, growing flowering plants alongside crop boundaries could provide additional feeding sites for the wasp. However, such plants would undoubtedly support additional prey species that could lower the impact of the beetles as predators of the cabbage root fly (Finch, 1988).

The main problem with all of the systems used until now to "enhance" the numbers of polyphagous predators and parasitoids, is that the various treatments have only added to the numbers of beneficial insects present rather than "enhancing" their effects as pest control agents. This raises the question of whether it will ever be possible to improve pest control by making crop boundaries more diverse, as the associations between the numbers of predators and their prey and the numbers of parasitoids and their hosts, is finely balanced in such systems. In general, insects only attain pest status in the types of unbalanced systems that occur in agriculture and, in particular, in large monocultures. Therefore, perhaps the only way to resolve this problem will be to treat the unbalanced systems with an unbalanced control measure, such as the release of higher than normal numbers of laboratory-reared predators/parasitoids. At present we use specific insecticides to control the cabbage root fly, so by analogy we may also need to use specific, rather than general, biological agents for the types of pest control needed in ephemeral cultivated crops.

Many authors have indicated that the beetle *A. bilineata* is probably the most appropriate parasitoid to rear and release against the cabbage root fly. However, the published data indicate that this would be true only in localities where the wasp *T. rapae* does not occur. Although such localities can be found in Canada (Wishart & Monteith, 1954), the wasp was found to be the dominant species in 10 countries in northern Europe (Finch *et al.*, 1985). A second drawback to releasing the beetle *A. bilineata* as a predator, is that it would have to be released at the start of each and every fly generation as, being a pupal parasitoid, no matter how early it is released its offspring will always emerge 2-3 weeks later than the pest fly.

The second alternative is to release the wasp, but as this is not predatory, the benefits of high levels of parasitism would accrue only in subsequent generations. There does, however, seem to be considerable scope for increasing levels of parasitization by the wasp, as no beetles emerged from samples of cabbage root fly pupae collected from Belgium, Denmark, Eire, Germany, Northern Ireland and The Netherlands, and in many of these countries the levels of parasitzation by the wasp rarely exceeded 5% (Finch, unpublished data). Therefore, in these countries, competition between the two major parasitoids appeared to be of little importance. Presumably the best way to reduce the competition from the beetle

A. bilineata in a specific locality in the UK would be to release wasps early into a crop so they parasitize a higher proportion of the early-instars of the fly and hence reduce considerably those instances of multiparasitism where the beetle larva was likely to survive. In addition, if *T. rapae* is to be reared in the laboratory, it would help if the fly larvae could be reared on an artificial diet to make them more accessible to the wasps. Alternatively, high levels of parasitism may be easy to achieve if the wasps will attack first-instar larvae shortly after they emerge from the eggs.

The third parasitoid species, *A. bipustulata*, has the advantage that it overwinters as the adult and hence is active when the fly is laying in the early spring. Whether this beetle can be used in conjunction with the wasp to give adequate levels of control requires testing. What is certain, however, is that if attempts are made to arrest this beetle around the base of brassica plants by adding organic material, something other than mustard meal (Ahlstrom-Olsson & Jonasson, 1992) should be used, as when Ahlstrom-Olsson tested this material at Horticulture Research International Wellesbourne in 1992, the mustard meal attracted preferentially the cabbage root fly and hence plants surrounded by mustard meal were damaged more severely than plants without mustard meal.

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