Biological Control 49 (2009) 219–226

Contents lists available at ScienceDirect

Biological Control

journal homepage: www.elsevier.com/locate/ybcon

Field evaluation of the combined deterrent and attractive effects of dimethyl disulfide on *Delia radicum* and its natural enemies

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A R T I C L E I N F O

Article history:
Received 22 July 2008
Accepted 21 January 2009
Available online 4 February 2009

Keywords:
Delia radicum
Aleochara bilineata
Aleochara bipustulata
Bembidion spp.
Dimethyl disulfide
Infochemicals
Pest control

A B S T R A C T

Delia radicum (L. 1758) is a major pest of cabbage crops in northern Europe. Due to more constraining laws relating to insecticide use, new strategies to control this pest are urgently needed. Manipulating insect behavior through infochemicals is a promising approach. The recent identification of dimethyl disulfide (DMDS) as a compound that both attracts the main predators of *D. radicum* and inhibits oviposition by the fly gives a challenging opportunity to develop such strategy. The aim of the present study was to confirm such potential of DMDS, in the field. Through the 8 weeks of the first egg laying peak of the fly we assessed, the potential of artificially increasing the levels of this molecule in the close vicinity of broccoli plants to 1/attract predators, 2/stimulate predatory activity and 3/limit damage done by the fly. Despite a lower number of *D. radicum* eggs as food resource, DMDS effectively increased predator catches in treated plots (119 *Aleochara bilineata* (Gyllenhal, 1810) caught in treated plot, while only 21 in control plots). However, damages done by the fly were of the same magnitude order in treated plots than in control ones. Number of *D. radicum* larvae and pupae recovered in plant roots were similar, despite the important decrease in eggs laid. This result, together with the observation that the numbers of eggs predated in artificial patches were lowered in the presence of the molecule, seems to indicate that increasing DMDS amounts disturbed the foraging activity of the fly predators. Consequences of these findings for the future of DMDS use in crop protection against *D. radicum* are discussed.

1. Introduction

Interactions among organisms are under the strong influence of chemical compounds. In insect–plant interactions, volatile chemicals play a key role in foraging activities. These volatiles, originating either from conspecifics, preys or their habitat, are often used by foragers to make useful decisions for finding resources or avoiding danger (e.g., Bell and Cardé, 1984; Vet and Dicke, 1992; Dicke and van Loon, 2000. The importance of these infochemicals in insect–insect and plant–insect interactions led to the emergence of new pest management practices (e.g. Lewis and Martin, 1990; Nordlund et al., 1981; Foster and Harris, 1997. In particular, artificially added infochemicals were used with success as pest attractants in mass trapping strategies involving Lepidopteran sex pheromones and Coleopteran aggregation pheromones (e.g. Howse et al., 1996. Using the deterrent activity of some synthetic volatiles like alarm pheromones (*E*-β-farnesene) also gave successes in crop protection against aphids (Griffiths et al., 1989; Pickett et al., 1997). Another strategy often considered is the use of volatiles which are attractive for natural enemies of the pest (parasitoids and/or predators) to enhance their colonization of crops and their natural limiting effect on pest populations (e.g. Dicke et al., 1990; Degenhardt et al., 2003; Turlings and Ton, 2006. Although this strategy was used early to manipulate parasitoids (Lewis and Nordlund, 1984), it was only recently used with success to attract predators by James and co-authors in hop yards (2005). In addition, to increase the potential of such approach it has been suggested to combine different strategies using infochemicals (Pickett et al., 1997). For example, the stimulo deterrent diversionary strategy (SDDS) proposes the use of different odors to simultaneously push a pest from harvestable crops while, at the same time, pull them in a sacrificed plot (Miller and Cowles, 1990; Cook et al., 2007).

Nevertheless, except for the case of mass trapping strategies, using infochemicals generally lacked efficiency when compared to conventional crop protection with insecticides. However, there is growing evidence of adverse effects of the intensive use of insecticides (Cooper, 1991) ; Edwards and Tchounwou, 2005, leading to more and more constraining laws. New solutions based on our increasing knowledge of pest biology and ecology need to be found.

Delia radicum, the cabbage root fly, is an economically important pest of brassicaceae crops in northern countries of the Holarctic region. The fly lays its eggs on the soil in the vicinity of

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1049-9644/$ - see front matter © 2009 Published by Elsevier Inc.
doi:10.1016/j.biocontrol.2009.01.013

brassicaceae stems. Larval development takes place inside the plant roots and can lead to important yield losses. There are typically two to three peaks of eggs laying by the fly during the whole season of crop plantation (from the middle of March to the end of September). The first peak, corresponding to the emergence of hibernating pupae, is of major concern. Damages occur on a very valuable crop (early vegetables) and can cause up to 100% losses due to the small size of plants at the time of attack. The use of the main insecticide (the organophosphorous Chlorfenvinphos, i.e. 2-chloro-1-(2,4-dichlorophenyl)vinyl diethyl phosphate) against this pest has been banned in all the European Union since December 2007. Recent studies have showed the potential use of dimethyl disulfide (DMDS) in a biocontrol strategy against *D. radicum* (Ferry et al., 2007, in preparation). This compound is emitted in large amounts by roots heavily infested by the cabbage root fly. In the field, we found that DMDS is attractive for the main natural enemies of the fly (Ferry et al., 2007), i.e carabidae belonging to the genus *Bembidion* (Latreille, 1802) acting as generalist predators of eggs and larvae, and *Aleochara bilineata* (Gyllenhal, 1810) and *A. bibustulata* (L., 1761), two staphilinids that are both generalist predators and parasitoids of the fly pupae. DMDS was also found to be an oviposition repellent for the fly (Ferry et al., in preparation). These two coupled effects (repel the pest and attract the predators) may offer a great advantage in comparison to other strategies using infochemicals targeting only one of the two. The present study investigates the potential for using DMDS as an infochemical against *D. radicum*. A field trial was conducted to investigate under cropping conditions the potential of DMDS for both limiting oviposition by the fly and improving predator occurrence and activity. The effect of DMDS use on crop quality was also assessed.

2. Materials and methods

2.1. Plot description

The field experiment took place in the experimental station of La Rimbaudais, Saint Méloir des Ondes, France, in the heart of an important zone of cabbage production (001°54 W/48°39 N). The field consisted of a broccoli (*Brassica oleracea*, L. 1753; var. Monopoly) plot cultivated in a traditional way. One month old seedlings were planted in the field the 12th of April at a density of 4.3 plants per m^2 on a 40 × 80 m field. One week after plantation, the plot was treated at 2L/Ha with the herbicide Butisan® (active compound: matazachlore) to limit further machine intervention in the experimental plot. No insecticide was used, neither as seed coating (frequently used by non-organic farmers) nor as sprays in the field. The crop was maintained until the 1st of June, at a date corresponding to the end of the first peak of *D. radicum* egg laying.

We used a randomized block design consisting of four blocks with two treatments in each block. Blocks were separated from each other by 5 m of bare soil. Elementary plots in the blocks were also separated by a non cropped band of 3 m. Elementary plots consisted of a 14 × 15 m cultivated surface (16 rows with around 18 plants per row). Treatments were applied in the 10 middle rows and the 12 middle plants of each row of these plots, leading to an extra buffer zone of untreated plants around the treated ones (three rows and 2.5 m at the end of the rows) (Fig. 1). The firsts rows and the firsts plants in rows at the boundary of the treated zone were counted as ‘margin’ and where not taken into account for the measurements.

Treatments consisted of adding an open Eppendorf tube filled with 0.5 mL of DMDS diluted in paraffin oil (1:250), at a distance

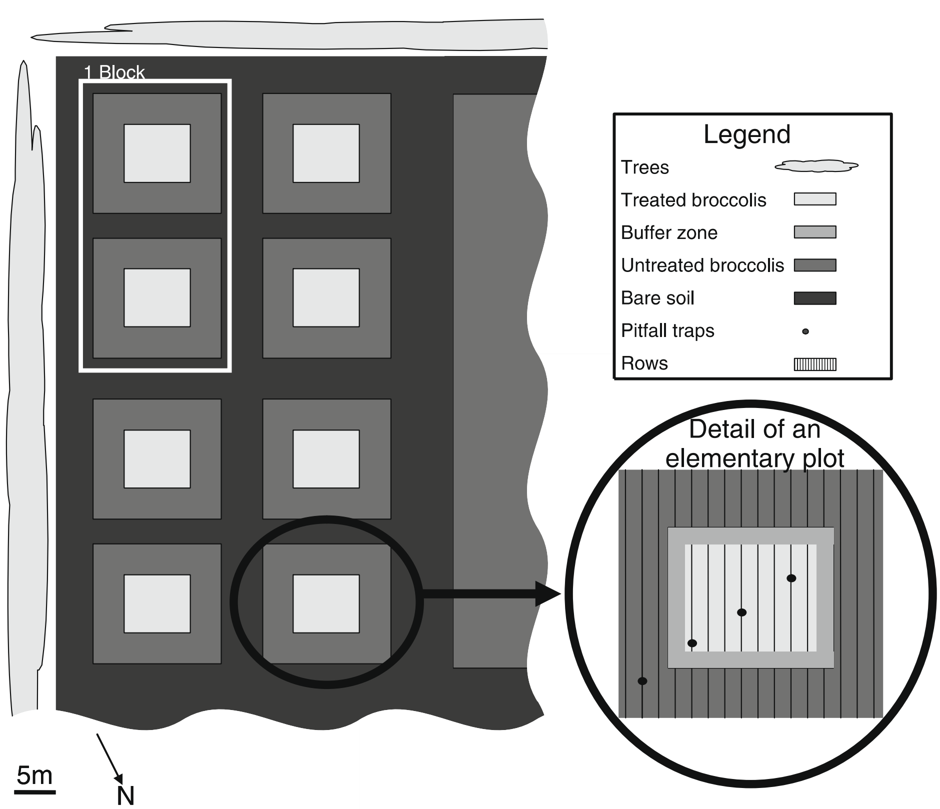

Fig. 1. Diagram of the experimental field. It consists of four blocs, each containing a control plot and a DMDS treated plot. Each bloc and each elementary plot inside blocs are separated by a non cropped zone. Elementary plots consist of a treated zone surrounded by non-treated plants (referred to in text as 'buffer zone'). The edge of the treated area was considered as margin and was not taken into account for measurements.