

**ONION MAGGOT *DELIA ANTIQUA* (DIPTERA: ANTHOMYIIDAE) ADULT
ACTIVITY AND OVIPOSITION IN NEW YORK ONION FIELDS:
IMPLICATIONS FOR MANAGEMENT**

A Thesis

Presented to the Faculty of the Graduate School

of Cornell University

in Partial Fulfillment of the Requirements for the Degree of

Master of Science

by

Benjamin Paul Werling

January 2004

© 2004 Benjamin Paul Werling

ABSTRACT

Insect pest activity is often concentrated in certain areas within crops. Past research has suggested that onion maggot, *Delia antiqua* (Meigen) (Diptera: Anthomyiidae), adult activity and oviposition may be concentrated along onion field edges and may be affected by the surrounding landscape. To examine this further yellow sticky cards were placed at varying distances along transects extending from edges of commercial onion fields that either bordered or did not border woods. Sticky cards were collected and replaced weekly throughout the 2002 and 2003 growing season. To determine if oviposition by first-generation onion maggot is concentrated along wooded field edges, potted onion plants were placed along edges and in centers of onion fields that either bordered or did not border woods. Results indicate that adult activity of both sexes is concentrated along edges of onion fields during the first- and second-generations of onion maggot, especially next to woods in the first generation. These “edge effects” lessened as the season progressed and were not present during the third-generation. Oviposition was uniform with respect to distance from the edge and type of bordering habitat. It may be possible to limit application of insecticides targeting adult onion maggot to wooded field edges during the first-generation or to deploy cultural controls here.

A delay in planting the onion crop has been recommended, but never evaluated, as a method of reducing onion maggot damage. A delay in planting will also result in plants being younger at the time onion maggot becomes damaging, and plants may be more susceptible to onion maggot when they are young. In contrast, planting early might result in onions being older and inherently more tolerant of onion maggot damage. To determine how planting date affects levels of onion maggot damage, damage was evaluated in three sequentially-planted onion plots in a commercial onion field in 2003. Earliest plantings coincided with the earliest

commercial sowing date and delayed plantings were made three and six weeks later. To determine how plant age affects resistance to onion maggot, damage to onions of different ages was evaluated in the laboratory after they were infested with varying densities of onion maggot eggs. Ovipositional preference by onion maggot for differently aged onions was also investigated in the lab to determine if a preference for early plantings could result in egg densities being greater on these plants in the field. Onion maggot damage was high in earliest plantings (37%), lower but economically unacceptable in intermediate plantings (21%), and lowest in late plantings (2%). While the latest planting provided acceptable control, planting this late is not currently feasible for New York growers because they prefer to plant as early as possible to maximize size of onion bulbs at harvest. Onion maggot laid more eggs on older than younger plants in choice tests; therefore more eggs may be laid on early vs. delayed plantings in the field. Older plants were more resistant to maggot attack than younger plants at low egg densities, but not at high ones. This may explain why early plantings are more heavily damaged than delayed ones in the field; greater numbers of eggs may be laid on early plantings if they are preferred for oviposition, resulting in damage being higher in early than delayed plantings.

BIOGRAPHICAL SKETCH

Ben Werling was born in Evanston, Illinois on the 23rd of January in 1979. After graduating in 1997 from Lutheran high School Westland, he attended Luther College in Decorah, Iowa, receiving his B. A. in Biology in 2001. In 2001 he started working towards his M. S. in Entomology at Cornell University, working with Brian Nault at the New York State Agricultural Experiment Station to complete the work detailed in this thesis.

This thesis is dedicated to my parents who have taught me, among many other things, to always keep my eyes open to the everyday beauty and complexity of the world we live in and those we share it with.

ACKNOWLEDGEMENTS

I owe a heartfelt thanks to the many people who have helped me in the completion of my research. Firstly I thank my advisor, Brian Nault, for his invaluable guidance, support, advice and encouragement. I also thank my committee members Jan Nyrop and Alan Taylor for their input and advice throughout the course of my time here. Brian and my committee members have helped me attain the basic tools I need to become a research scientist. I would also like to thank the growers who have allowed me to conduct research on their land and Cornell Cooperative Extension agents Jan van der Heide and Carol MacNeil for advice and help obtaining field sites. Thanks also to Cornell University statistical consultant Françoise Vermeulen for her help in constructing analyses appropriate for our data.

I also owe a big thank you to all those who have donated their sweat and smiles in helping me complete my research including Mary Lou Hessney, Kathryn Straight, Shirley Lewis, Eric Smith and Michael Poole. Thank you also to all the staff of the experiment station who have provided a friendly environment for me to work in.

I would like to thank my family and the multitude of wonderful people who I am privileged to be friends with as well. Thank you for your support in this and all of my endeavors. I also owe a debt of gratitude to those teachers who have encouraged me in the past to continue my studies in the field of biology.

Finally, I would like to thank the Department of Entomology of the New York State Agricultural Experiment station for funding this work.

TABLE OF CONTENTS

Biographical Sketch.....	iii
Dedication.....	iv
Acknowledgements.....	v
List of Tables.....	vii
List of Figures.....	viii
I. Introduction.....	1
References Cited.....	9
II. Spatial and temporal patterns of onion maggot, <i>Delia antiqua</i> (Diptera: Anthomyiidae), adult activity and oviposition within onion fields that vary in bordering habitat.....	12
Introduction.....	12
Materials and Methods.....	14
Results.....	22
Discussion.....	38
References Cited.....	49
III. Effects of onion plant age on onion maggot damage in the field and laboratory.....	53
Introduction.....	53
Materials and Methods.....	55
Results.....	59
Discussion.....	64
References Cited.....	69

LIST OF TABLES

- 2.1 Significance of effect of bordering habiatat, distance from the field edge and sampling date on numbers of male and female first-, second- and third-generation onion maggot, *Delia antiqua*, flies caught per sticky card per day during 2002 in New York commercial onion fields.....24
- 2.2 Significance of effect of bordering habiatat, distance from the field edge and sampling date on numbers of male and female first-, second- and third-generation onion maggot, *Delia antiqua*, flies caught per sticky card per day during 2003 in New York commercial onion fields.....25
- 2.3 Significance of effect of bordering habitat, distance from the field edge and run of experiment and their interactions on number of onion maggot, *Delia antiqua*, eggs laid per sentinel onion plant during 2003 in New York commercial onion fields.....39

LIST OF FIGURES

- 2.1 Mean (\pm SE) number of male and female onion maggot flies caught per sticky card per day for each sampling date in 2002 and 2003. Dotted vertical lines indicate estimated divisions between first- and second- and second- and third-generations of onion maggot, *Delia antiqua*, in New York.....19
- 2.2 Mean percentage of the total number of male and female first-, second- and third-generation onion maggot, *Delia antiqua*, flies captured in onion fields bordering or not bordering woods at varying distances from the field edge in New York in 2002.....26
- 2.3 Mean percentage of the total number of male and female first-, second- and third-generation onion maggot, *Delia antiqua*, flies captured in onion fields bordering or not bordering woods at varying distances from the field edge in New York in 2003.....29
- 2.4 Mean number of male and female onion maggot, *Delia antiqua*, flies caught per sticky card per day in commercial onion fields bordered and not bordered by woods for each sampling date within the first generation in New York in 2002.....34
- 2.5 Mean number of male and female onion maggot, *Delia antiqua*, flies caught per sticky card per day at five distances from edges of commercial onion fields for each sampling date within the first-generation in New York in 2002.....36
- 2.6 Mean number of onion maggot, *Delia antiqua*, eggs laid per plant per day on sentinel onion plants positioned at two distances from edges of commercial onion fields that either bordered or did not border woods in New York in 2003 for the first (a) and second (b) run of the experiment.....40
- 3.1 Mean cumulative percentage of early, middle, and late-planted onions damaged by onion maggot, *Delia antiqua*, and mean number of female onion maggot flies caught per sticky card per day for each sampling date.....60
- 3.2 Percentage of plants damaged by onion maggot, *Delia antiqua*, for two, four, six and eight week old plants inoculated with two, five and ten onion maggot eggs per plant.....63
- 3.3 Mean (\pm SE) number of onion maggot, *Delia antiqua*, eggs laid on plants the size of middle and early-planted onions at peak first-generation oviposition..65

CHAPTER ONE INTRODUCTION

Biology and pest status of *Delia antiqua*

Onion maggot, *Delia antiqua* (Meigen) (Diptera: Anthomyiidae), is an oligophagous insect specializing on plants within the genus *Allium* (Alliaceae) such as onion, *A. cepa* (L.), leek, *A. ameloparsum* (L.), garlic, *A. sativum* (L.), chives, *A. schoenoprasum* (L.) and Japanese bunching onion, *A. fistulosum* (L.) (Loosjes, 1976). Females use a variety of cues associated with hosts to locate plants suitable for oviposition, potentially laying several hundred eggs during their two to four week lifespan (Miller & Harris, 1985; Hoffman et al., 1996). These are typically deposited in batches of two to four eggs per plant (Mowry et al., 1989). Hatching larvae then feed internally or externally on subterranean tissue of these or nearby hosts, developing through three instars in two to three weeks and later pupating in the soil (Hoffman et al., 1996). Eclosion occurs two to four weeks later. Overwintering occurs in the pupal stage.

Onion maggot is the principal insect pest of onion in north temperate regions such as the northeastern United States (Eckenrode, 1988). This pest constrains onion production because infestations are likely to cause significant economic injury if not controlled (Eckenrode, 1985), and control has become challenging due to insecticide resistance (Ellis & Eckenrode, 1979; Harris et al., 1982; Walters & Eckenrode, 1996). Onion maggot will commonly reduce stands of untreated onions by 20 to 60% (Taylor et al., 2001), and levels above 90% in portions of fields have been reported (Hoffman et al., 1996).

New York onion maggot populations are trivoltine (Eckenrode et al., 1975). First-generation maggots, which feed on newly emerged seedlings, generally are the most destructive and a single maggot can kill approximately 10 onion plants (Workman, 1958). Rates of onion maggot damage decrease as crop plants mature

(Loosjes, 1976), largely because older plants are more resistant to penetration by larvae (Finch et al., 1986b; See Chapter 3). Females also prefer to oviposit on previously damaged bulbs, so that many maggots of the second and third generation are likely maintained on plants that have already been infested (Hausmann & Miller, 1989). For these reasons the most intensive control measures are targeted at first-generation maggots.

There are very few effective and practical non-chemical methods for control of onion maggot. Natural enemies may play a role in limiting onion maggot abundance (Hoffmann et al., 1996). The entomopathogenic fungus *Entomophthora muscae* (Cohn), for example, has exhibited potential for reduction of onion maggot populations (Carruthers, 1981). Natural enemies such as the pupal parasitoid *Alleochara bilineata* (Gyll.) (Coleoptera: Staphylinidae) and the generalist predator *Bembidion quadrimaculatum* (L.) (Coleoptera: Carabidae) can cause high levels of onion maggot mortality as well (Perron, 1972; Grafius & Warner, 1989). However, insecticide, herbicide and fungicide use associated with onion production may cause differentially high mortality of *E. muscae* and insect natural enemies compared with onion maggot (Carruthers et al., 1985).

Cultural controls have also been developed for onion maggot but do not play a major role in its control. Proper disposal of cull onions left in the field after harvest is important to minimize food available to third-generation maggots, which complete development after harvest (Finch & Eckenrode, 1985). Crop rotation is a highly effective means of cultural control but has not been adopted by most New York growers because soils optimal for onion production are limited and other crops are less profitable (Martinson et al., 1988; Eckenrode & Nyrop, 1995). Trap cropping with volunteer onions has also been considered in the past as a potential method of onion maggot control (Mowry, 1993). However, such a trap crop would be unmarketable

and would likely be ineffective without the use of insecticides (Miller & Cowles, 1990). Finally, a delay in spring-planting may result in reduced onion maggot damage (Doane & Chapman, 1952) but may or may not be practical since most New York growers prefer to plant crops early to allow ample time for onion growth; the effectiveness of this technique has not been thoroughly examined, making evaluation of its potential difficult.

Other non-chemical control strategies have been investigated for onion maggot with only partial success. Plant resistance has been investigated as a way of reducing onion maggot damage, but levels of resistance in available cultivars were slight and inconsistent (Walters & Eckenrode, 1996). A large body of work conducted in the Netherlands indicates that release of sterile male onion maggot flies is effective at reducing local populations of this pest (Loosjes, 1976). However, this technique requires a large investment of time and money. Finally, non-woven fiber barriers have proven to be very effective at protecting onion seedlings from ovipositing onion maggot flies, but application using current technology is costly and impractical (Hoffmann et al., 2001). Thus, despite a large body of research on non-chemical controls for onion maggot, most New York growers currently depend on insecticides for control since few other techniques have been shown to be both effective and practical (Eckenrode & Nyrop, 1995).

Currently, there are only two insecticides recommended for control, chlorpyrifos and cyromazine (Taylor et al., 2001). Chlorpyrifos and related organophosphates have been used for over 20 years and resistance to this class has become widespread (Eckenrode & Nyrop, 1995). In contrast, cyromazine is an insect-growth regulator with a novel mode of action and is currently effective for control of onion maggot (Taylor et al., 2001). Chlorpyrifos is commonly applied as an in-furrow drench at planting (Ellis & Eckenrode, 1979), while cyromazine is available

as a seed treatment (Taylor et al., 2001). Foliar sprays have also been used to control adult populations after the soil insecticide has lost effectiveness (Finch et al., 1986b). These sprays are of questionable utility, however, since flies are fairly mobile, may spend a large amount of time outside of fields, and have to be contacted with spray to be killed (Finch et al., 1986b).

In the northern US and Canada, onion is grown in small areas of high organic soil (muck) located in old lakebeds drained during the early 20th century. Lack of rotation has exacerbated problems with onion maggot because it overwinters within these fields (Finch & Eckenrode, 1985) and is unlikely to migrate far from these areas (Martinson et al., 1988). Although crop rotation significantly reduces onion maggot infestations (Ellis & Eckenrode, 1979), the absence of this practice has repeatedly subjected localized populations to the limited arsenal of available insecticides (Finch et al., 1986a; Eckenrode & Nyrop, 1995), leading to insecticide resistance in many populations (Harris et al., 1982; Eckenrode, 1985).

This resistance development has largely been mitigated in the past two decades through the use of new insecticides (Eckenrode & Nyrop, 1995). Changes in the regulatory climate, however, have made the development of new insecticides very costly, especially for minor, high value crops like onions. Thus it is unlikely that insecticide development will keep pace with onion maggot resistance in the future. The development of resistance management strategies in combination with alternatives to insecticide use is vital to preserve the effectiveness of current chemical controls and provide protection to onion crops in the advent of increased resistance.

Spatial patterns of *Delia antiqua* adult activity and oviposition

Insect pest activity is often concentrated in certain locations within crop fields. Pest damage, for example, is often greater along field edges than in field centers (Slosser et al., 1987). Adult insect activity can be concentrated along crop edges as

well (Sciarretta et al., 2001). Knowledge of these patterns can be exploited to reduce insecticide use by limiting insecticide applications to areas of high pest activity (Shukla & Tandon, 1985; Tandon & Shukla, 1989) or through the use of alternative controls which take advantage of pests being concentrated in certain areas, such as perimeter trap cropping (Boucher et al., 2003). Similar approaches may be applicable for control of onion maggot if their activity is concentrated in certain areas, allowing insecticide use to be reduced.

Onion maggot adult activity may be concentrated along field edges. On a per field basis, more onion maggot flies have been trapped along field edges than in field centers (Loosjes, 1976; Whitfield, 1981; Finch et al., 1986a; Vernon et al., 1987; Vernon et al., 1989). However, this edge effect in trap catch does not occur in all fields (Finch et al., 1986a) or along all edges within a field (Vernon et al., 1987; Vernon et al., 1989). This inconsistency may be explained by differences in the surrounding landscape. More specifically, fly activity may be more concentrated along wooded field edges than other types of bordering habitat. For example, in New York Finch et al. (1986a) observed a high number of onion maggot flies along an onion field edge that bordered a hedgerow of trees, but fewer were observed as distance from that field edge toward the field center increased. In contrast, onion maggot flies were distributed evenly (with respect to distance from the field edge) in an onion field not bordered by trees. Determining how consistent this edge effect is across time and space and where it most often occurs is important if this information is to be used to make management decisions.

Damage in commercial onion fields is often greater along field edges than in field centers, suggesting that oviposition may be concentrated along field edges in the same locations as adult activity (Finch et al., 1986b). However, no studies have documented that the above damage patterns result from differentially high oviposition

along field edges relative to field centers. Furthermore, damage is not consistently greatest along field edges (Loosjes, 1976). Changes in the neighboring landscape may affect oviposition patterns in a fashion similar to that hypothesized for adult flight activity.

Planting date

Most New York onions are grown directly from seed planted in fields from early-April through mid-May (Hoffmann et al., 1996). The choice of planting date has implications for bulb size at harvest and the variety of onion planted, because different varieties mature at different times of year (Brewster, 1994). Planting at different dates during a particular season may also have implications for pest-crop interactions because it will alter the stage of plants available to crop-plant herbivores during their periods of peak activity. In extreme cases, it might even be possible to plant crops before or after pest populations peak. These situations raise the possibility of controlling insect pests by altering crop planting date in a way unfavorable to them.

Delaying planting as long as possible in the spring has been recommended as a method of cultural control for onion maggot (Doane & Chapman, 1952). The goal of this strategy is to allow the onion crop to escape infestation by first-generation onion maggots by reducing the time plants are exposed to oviposition by spring-emerging flies. If planting onions late does indeed reduce damage by onion maggot, it could provide a much needed method of cultural control for this pest. However, the effectiveness of this technique has never been evaluated. It is important to know whether this technique reduces onion maggot damage to an economically acceptable level before it is recommended to growers.

Onions may become harder for onion maggot to penetrate, and thus more resistant to attack, as they grow and mature. For example in New York, Finch et al. (1986) found that 37% of onion maggot eggs placed on plants taken from fields on 19

July survived to pupation, while no pupae were produced on older plants removed from these fields on 24 August. In contrast to the recommendation of planting late to avoid onion maggot attack (Doane & Chapman 1952), these results suggest that it is preferable for growers to plant onions early in the season so that onions are as old as possible, and thus maximally resistant to onion maggot, by the time of first maggot attack.

Paradoxically, damage by onion maggot typically occurs more commonly in early-planted onion fields than in late-planted ones. Thus, some factor must be causing the inherent resistance of older plants to onion maggot to break down. Onion maggot lays more eggs on larger plants when offered a choice between these and smaller plants (Harris et al., 1987). Early-planted onions will be larger than late-planted ones at peak oviposition of the first generation of onion maggot, thus densities of first-generation onion maggot eggs may be greater on early- than late-planted onions. The increased resistance of older, earlier-planted onions as compared with younger, later-planted ones may then be overcome by high densities of invading larvae.

A late planting date could provide a much needed method of cultural control for onion maggot. Evaluation of its potential to reduce maggot damage is essential for it to be effectively used as a control method. Understanding how plant age affects ovipositional preference of onion maggots and resistance to maggot attack would help explain why a late planting date would or would not be an effective strategy. Finally, a late planting date may be combined with other less chemically-intense strategies to provide a more sustainable way to manage onion maggot. These additional strategies may include those requiring a sound knowledge of the spatial distribution of onion maggot activity within fields.

Research objectives:

The overall goal of research detailed in the following chapters was to add to the basic body of knowledge about onion maggot ecology and control for the purpose of future development of sustainable management practices. The objectives of research detailed in the second chapter were to determine if onion maggot flight activity and oviposition (1) differ along edges of onion fields with and without bordering woods, and (2) change with increasing distance from edges of onion fields. The meeting of these objectives could enable areas within fields where flies consistently are most active and lay high numbers of eggs to be targeted for control.

The objectives of research detailed in the third chapter were to determine (1) the relationship between onion planting date and onion maggot damage in the field, (2) how onion plant age affects resistance to onion maggot when plants are infested at a variety of egg densities, and (3) if flies prefer to oviposit on early versus late-planted onions. Meeting these objectives would enable pest managers to assess the potential of late planting as a control measure for onion maggot.

References

- Carruthers, RI (1981) The Biology and Ecology of *Entomophthora muscae* (Cohn) in the Onion Agroecosystem. PhD Dissertation. Michigan State University, MI, USA.
- Carruthers RI, Whitfield GH & Haynes DL (1985) Pesticide induced mortality of natural enemies of the onion maggot, *Delia antiqua* [Diptera: Anthomyiidae]. *Entomophaga* 30: 151-161.
- Cowles RS & Miller JR (1992) Diverting *Delia antiqua* (Diptera: Anthomyiidae) oviposition with cull onions: Field studies on planting depth and a greenhouse test of the stimulo-deterrent concept. *Environmental Entomology* 21: 453-460.
- Doane CC & Chapman RK (1952) Dusts and late planting control onion maggots. Bulletin, no. 498. University of Wisconsin, Madison, Agricultural Experiment Station, WI, USA.
- Eckenrode CJ (1985) Onion maggot damage increasing: Pesticide resistance calls for integrated pest controls. *American Vegetable Grower* June: 10-12.
- Eckenrode CJ (1988) *Delia antiqua* (Meigen): An increasing threat in North America. In: Narkiewicz-Jodko J & Nawrocka B (eds), *International Symposium on Diptera Pests in Vegetable Crops*. International Society of Horticultural Science, Skierniowice, Poland, pp. 27-30.
- Eckenrode CJ & Nyrop JP (1995) Onion maggot management in New York, Michigan and Wisconsin. *New York's Food & Life Sciences Bulletin*, no. 144. Cornell University, NY, USA.
- Eckenrode CJ, Vea EV & Stone KW (1975) Population trends of onion maggots correlated with air thermal unit accumulations. *Environmental Entomology* 4: 785-789.
- Ellis PR & Eckenrode CJ (1979) The onion maggot and its control in New York. *New York's Food and Life Sciences Bulletin*, no. 79. Cornell University, NY, USA.
- Finch S, Cadoux ME, Eckenrode CJ & Spittler TD (1986b) Appraisal of current strategies for controlling onion maggot (Diptera: Anthomyiidae) in New York state. *Journal of Economic Entomology* 79: 736-740.
- Finch S & Eckenrode CJ (1985) Influence of unharvested, cull-pile, and volunteer onions on populations of onion maggot (Diptera: Anthomyiidae). *Journal of Economic Entomology* 78: 542-546.

Finch S, Eckenrode CJ & Cadoux ME (1986a) Behavior of onion maggot (Diptera: Anthomyiidae) in commercial onion fields treated regularly with parathion sprays. *Journal of Economic Entomology* 79: 107-113.

Grafius E & Warner FW (1989) Predation by *Bembidion quadrimaculatum* (Coleoptera: Carabidae) on *Delia antiqua* (Diptera: Anthomyiidae). *Environmental Entomology* 18: 1056-1059.

Harris MO, Miller JR & de Ponti OMB (1987) Mechanisms of resistance to onion fly egg-laying. *Entomologia Experimentalis et Applicata* 43: 279-286.

Harris MO, Tolman JA & Svec HJ (1982) Onion maggot (Diptera: Anthomyiidae) resistance to some insecticides following selection with parathion or carbofuran. *The Canadian Entomologist* 114: 681-685.

Hausmann SM & Miller JR (1989) Ovipositional preference and larval survival of the onion maggot (Diptera: Anthomyiidae) as influenced by previous maggot feeding. *Journal of Economic Entomology* 82: 426-429.

Hoffmann MP, Kuhar TP, Baird JM, Gardner J, Schwartz P & Shelton AM (2001) Nonwoven fiber barriers for control of cabbage maggot and onion maggot (Diptera: Anthomyiidae). *Journal of Economic Entomology* 94: 1485-1491.

Hoffmann MP, Petzoldt CH & Frodsham AC (1996) *Integrated Pest Management for Onions*. Cornell Cooperative Extension, NY, USA.

Hokkanen HMT (1991) Trap cropping in pest management. *Annual Review of Entomology* 36: 119-138.

Loosjes, M (1976) *Ecology and Genetic Control of the Onion Fly, Delia antiqua (Meig.)*. Center for Agricultural Publishing and Documentation, Wageningen, The Netherlands.

Martinson TE, Nyrop JP & Eckenrode CJ (1988) Dispersal of the onion fly (Diptera: Anthomyiidae) and larval damage in rotated onion fields. *Journal of Economic Entomology* 81: 508-514.

Martinson TE, Nyrop JP & Eckenrode CJ (1989) Long-range host-finding behavior and colonization of onion fields by *Delia antiqua* (Diptera: Anthomyiidae). *Journal of Economic Entomology* 82: 1111-1120.

Miller JR & Cowles RS (1990) Stimulo-deterrent diversion: A concept and its possible application to onion maggot control. *Journal of Chemical Ecology* 16: 3197-3212.

- Miller JR & Harris MO (1985) Viewing behavior-modifying chemicals in the context of behavior: Lessons from the onion fly. In: Acree TE & Soderlund DM (eds), *Semiochemistry: Flavors and Pheromones*. Walter de Gruyter, NY, USA, pp. 3-31.
- Mowry TM (1993) Ovipositional patterns and larval movement of *Delia antiqua* (Diptera: Anthomyiidae) on sprouted bulb and seedling onions. *Journal of Economic Entomology* 86: 1440-1445.
- Perron JP (1972) Effects of some ecological factors on populations of the onion maggot *Hylemya antiqua* (Meig) under field conditions in southwestern Quebec. *Annales de la Societe Entomologique Quebec* 17: 29-47.
- Shukla RP & Tandon PL (1985) Bioecology and management of the mango weevil *Sternochetus mangiferae* (Coleoptera: Curculionidae). *International Journal of Tropical Agriculture* 3: 293-303.
- Tandon PL & Shukla RP (1989) Spot application of insecticides for the management of mango stone weevil, *Sternochetus mangiferae* (Fabr.). *Acta Horticulturae* 231: 571-574.
- Taylor AG, Eckenrode CJ & Straub RW (2001) Seed coating technologies and treatments for onion: Challenges and progress. *HortScience* 36: 199-205.
- Vernon RS, Hall JW, Judd GJR & Bartel DL (1989) Improved monitoring program for *Delia antiqua* (Diptera: Anthomyiidae). *Journal of Economic Entomology* 82: 251-258.
- Vernon RS, Judd GJR & Borden JH (1987) Commercial monitoring program for the onion fly, *Delia antiqua* (Meigen) (Diptera: Anthomyiidae) in southwestern British Columbia. *Crop Protection* 6: 304-312.
- Walters TW & Eckenrode CJ (1996) Integrated management of the onion maggot (Diptera: Anthomyiidae). *Journal of Economic Entomology* 89: 1582-1586.
- Whitfield GH (1981) Spatial and Temporal Population Analysis of the Onion Maggot (*Hylemya antiqua* (Meigen)), in Michigan. PhD Dissertation. Michigan State University, MI, USA.
- Workman RB Jr. (1958) Biology of the Onion Maggot, *Hylemya antiqua* (Meigen) Under Field and Greenhouse Conditions. PhD Thesis. Oregon State University, OR, USA.

CHAPTER TWO

Spatial and temporal patterns of onion maggot, *Delia antiqua* (Diptera: Anthomyiidae), adult activity and oviposition within onion fields that vary in bordering habitat

Introduction

Onion maggot, *Delia antiqua* (Meigen), is a principal pest of onion, *Allium cepa* L., and other *Allium* sp. in north temperate regions such as the northern United States and Canada (Eckenrode, 1988). Onion maggot damages the onion crop when larvae feed on the portion of the plant below the soil surface. This feeding causes young plants to wilt and eventually die and older plants to develop distorted bulbs; feeding wounds can also allow entry by pathogens causing the bulb to rot (Hoffmann et al., 1996). There are three generations of onion maggot each year in New York (Eckenrode et al., 1975), but the first-generation is the most damaging (Loosjes, 1976; Liu et al., 1982). Control efforts are consequently focused on preventing damage caused by first-generation larvae.

Control of onion maggot currently relies almost entirely on the use of insecticides (Eckenrode & Nyrop, 1995). However, onion maggot has developed resistance to many insecticides, rendering them useless (Loosjes, 1976; Eckenrode, 1985). Widespread control failures have largely been avoided in the past two decades through the use of new insecticides like cyromazine (Eckenrode & Nyrop, 1995; Taylor et al., 2001), which is an insect growth regulator that currently provides control of onion maggots that are resistant to organophosphates (Yildirim & Hoy, 2003). However, it is unlikely that the development of new insecticide chemistries will keep pace with onion maggot resistance in the future, because changes in the regulatory climate have made the development of new insecticides very costly, especially for minor, high value crops like onions (Eckenrode & Nyrop, 1995). The development of

control strategies that reduce or provide alternatives to insecticide use is important to ensure the future sustainability of New York onion production. A thorough understanding of the behavior and ecology of onion maggot in onion fields is needed to provide insight into which alternative management strategies have potential for control.

Insect pest activity is often concentrated in certain locations within crop fields. Pest damage, for example, is often greater along field edges than in field centers (Slosser et al., 1987). Adult insect activity can be concentrated along crop edges as well (Sciarretta et al., 2001). Knowledge of these patterns can be exploited to reduce insecticide use by limiting insecticide applications to areas of high pest activity (Shukla & Tandon, 1985; Tandon & Shukla, 1989) or through the use of alternative controls which take advantage of pests being concentrated in certain areas, such as perimeter trap cropping (Boucher et al., 2003). Similar approaches may be applicable for control of onion maggot if their activity is concentrated in certain areas, allowing insecticide use to be reduced.

Onion maggot adult activity may be concentrated along field edges. On a per field basis, more onion maggot flies have been trapped along field edges than in field centers (Loosjes, 1976; Whitfield, 1981; Finch et al., 1986a; Vernon et al., 1987; Vernon et al., 1989). However, more flies are not always caught along field edges than in field centers (Finch et al., 1986a; Vernon et al., 1987; Vernon et al., 1989). This “edge effect” may only be present along certain edges within a field (Vernon et al., 1987; Vernon et al., 1989) and may not be present in some fields at all (Finch et al., 1986a). This inconsistency may be explained by differences in the surrounding landscape. More specifically, fly activity may be more concentrated along wooded field edges than other types of bordering habitat. For example in New York, Finch et al. (1986a) observed a high number of onion maggot flies along an onion field edge

that bordered a hedgerow of trees, but fewer were observed as distance from that field edge toward the field center increased. In contrast, onion maggot flies were distributed evenly with respect to distance from the field edge throughout an onion field not bordered by trees.

Damage by onion maggot in commercial onion fields is often greatest along field peripheries (Finch et al., 1986b), suggesting that oviposition follows a pattern similar to that of adult activity. However, no studies have documented that these damage patterns result from differentially high oviposition in these areas relative to field centers. Furthermore, damage is not consistently greatest along field edges (Loosjes, 1976). Changes in the neighboring habitat may affect oviposition patterns within onion fields in a fashion similar to that hypothesized for adult activity.

Our goal in conducting the research detailed below was to gain a better understanding of the spatial and temporal patterns of onion maggot adult activity and oviposition in typical New York onion fields. Specifically, we wished to determine if adult activity and oviposition are (1) greater in onion fields that border woods than those that do not and (2) greater along onion field edges than in onion field centers. If onion maggot activity and oviposition are consistently concentrated in certain areas, future control strategies could target onion maggot in these areas rather than across entire fields.

Materials and Methods

Patterns of adult activity within onion fields

Spatial and temporal patterns of onion maggot adult activity were investigated in five commercial onion farms in central New York in 2002 and 2003. In 2002, three farms were chosen in Oswego County, while one farm each was selected from Wayne and Yates Counties. These farms consist of continuous pockets of muck soil that have been subdivided into fields. Pairs of onion fields were selected within each farm, such

that one field bordered woods along one edge and the other was surrounded by non-wooded habitat (e.g. other vegetable crop fields) (n = total of 10 fields). Onion fields not bordered by woods were separated from other crops by either weedy ditches or by grassy areas. The same non-rotated onion fields were sampled in 2002 and 2003.

Onion maggot fly activity within each field was measured at five distances along transects extending from the field edge into the center of the field. This field edge either bordered woods or did not border woods (treatment described above). This design enabled us to compare overall onion maggot adult activity between onion fields that bordered woods or did not border woods and to determine if onion maggot fly activity decreased with increasing distance from the field edge. Structuring the experiment in this manner yielded five levels of distance from the onion field edge within the two treatment levels of bordering habitat (wooded and non-wooded).

Fly activity was monitored using 15 cm x 15 cm non-baited, yellow sticky cards (Olson Products, Medina, OH). Sticky cards were fastened to 91.4 cm-tall wooden stakes using plastic spring-loaded clamps (Woodworker's Supply, Casper, WY). Cards initially were positioned 13 cm above the ground, but were raised even with the top of the canopy as plants matured. Each card was considered as the sampling unit. Two transects (= two subsamples) of cards extending 184 m out from the field edge were placed within each field. Within each transect, five cards were spaced 46 m apart with the first card being placed within three meters of the edge (distance from the edge = 0 m for first position, 46 m for second etc.). Transects were spaced a minimum of 25 m and a maximum of 227 m apart within each field. Cards were collected and replaced weekly from the estimated start of first-generation fly emergence (15 May in 2002 and 13 May in 2003) until harvest (22 August 2002 and 1 September 2003). Numbers of onion maggot males and females per card were counted in the lab after collection. Onion maggot flies and their sex were identified

according to the key of Brooks (1971). Voucher specimens are held at Cornell University's New York State Agricultural Experiment Station in Geneva, New York.

Oviposition patterns of first-generation adults within onion fields

Patterns of oviposition by onion maggots in onion fields were examined only during the first-generation, which is the generation that causes the most serious damage to the crop (Loosjes, 1976; Liu et al., 1982). This study was conducted concurrently with the adult activity study at two of the Oswego County farms and the Wayne and Yates County farms in 2003 (n = 8 fields; four bordered woods and four did not). Number of eggs laid was assessed at only two distances from field edges: within 3 m of the edge and 184 m from the edge. This design enabled us to compare the overall number of onion maggot eggs laid in onion fields that bordered woods or did not border woods and to determine if oviposition was greater along field edges than within field centers.

Forty, large potted-onion plants (var. 'Empire Sweets') were placed within each field to attract ovipositing flies. Half of these "sentinel" onion plants were positioned along the field edge and half in the field center. The sampling unit was a single sentinel plant, so there were 20 subsamples per treatment. Sentinel plants within each treatment were situated in a line parallel to the field edge, with plants being spaced approximately one meter apart and the rim of the pots sunk even with the soil surface.

Sentinel onions were grown from bulbs harvested from experimental plots the previous year and stored through the winter at 4.4°C. Plants were grown from sprouted bulbs because second year growth of these biennials is especially attractive to ovipositing onion maggot flies (Mowry, 1993). Bulbs were planted in pots in late April to early May (= approximately one month prior to use) in a mixture of muck soil and potting soil mix in 15.24 cm diameter pots with their necks 5 cm below the soil

surface. Planting at this depth and allowing one month of growth to occur prior to use in the field yields plants maximally attractive to ovipositing flies (Cowles & Miller, 1992). Plants were subsequently maintained outdoors in cold frames and watered as necessary. Sentinel onions were also pierced with an awl three centimeters below the soil surface before placement in the field because damaged plants are more attractive to ovipositing flies than undamaged plants (Hausmann & Miller, 1989).

This experiment was conducted twice during the first generation of onion maggot beginning the week of 22 May. Plants from the first run were replaced with new plants the following week on 30 May and these plants were collected on 16 June. After collection, plants were taken back to the lab and the number of eggs laid per plant was recorded. The top three centimeters of soil around the base of each plant was removed and examined for eggs. The majority of onion maggot eggs are laid in this area (Havukkala et al., 1992). Soil was placed on a black surface and eggs were sorted through with a paintbrush. Onion maggot eggs are white and clearly visible against a black background. Preliminary experiments indicated that an equal number of eggs were retrieved using this method compared to floating eggs in muck soil using water. However, counting eggs by sorting through the soil with a paintbrush was much less time consuming than floating eggs. Onion foliage near the base of plants was also examined for eggs. To confirm that the eggs recovered from sentinel plants were onion maggot and not another insect species, up to 50 eggs were randomly selected from each treatment x run combination and reared to adulthood on chopped onion in a growth chamber (16L: 8D, 21°C, 60%rh). Ninety-five percent of insects surviving to adulthood were positively identified as onion maggot. Sap beetles (Coleoptera: Nitidulidae) were the only other species of insect reared from collected eggs. Sap beetle eggs were infrequently found on onions in our study, were readily

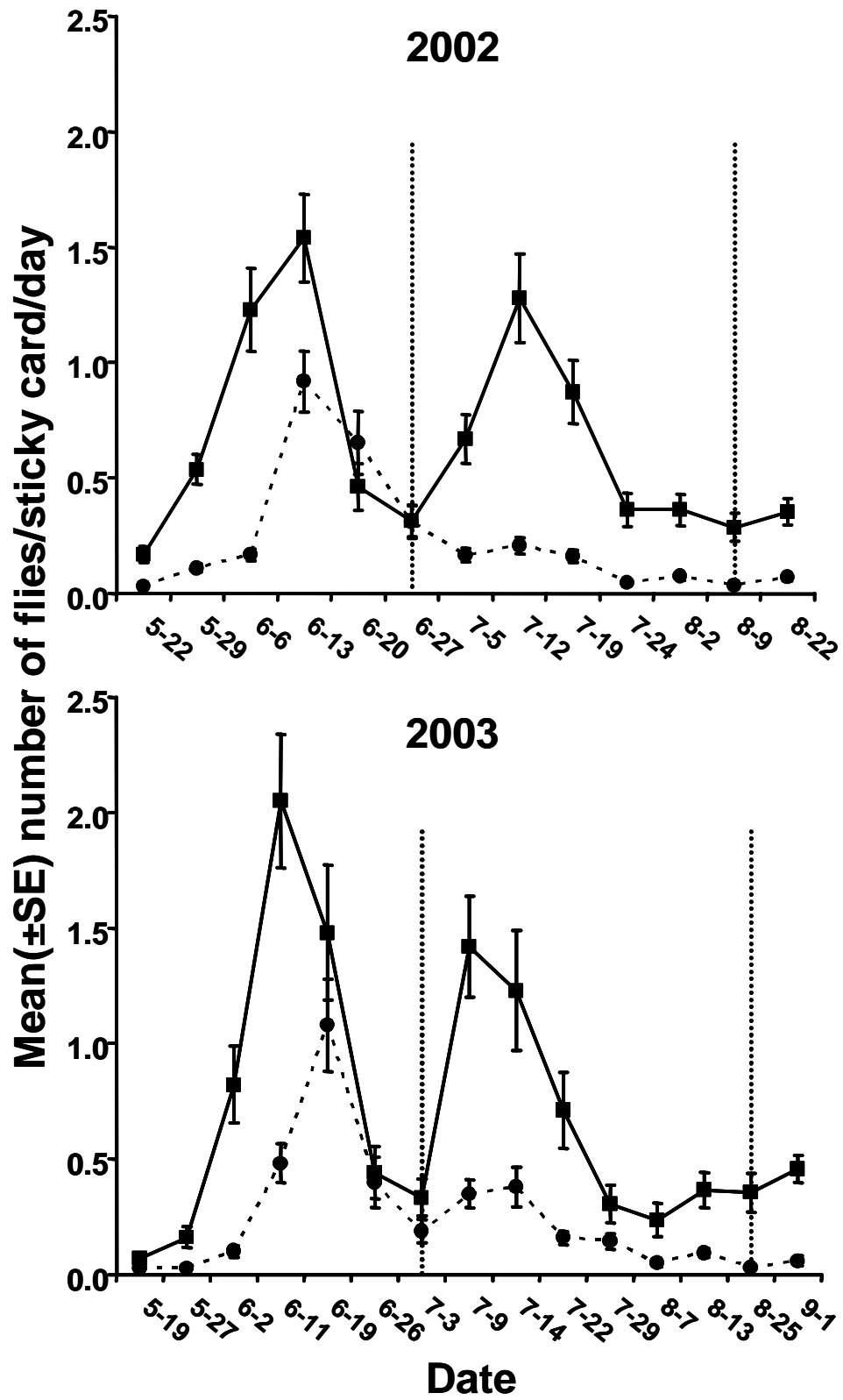
distinguishable from onion maggot eggs due to their color and texture, and were never recorded.

Data analyses

The mean number of adults captured per sticky card per day for each distance from the field edge was determined throughout the season. A rise and fall in numbers caught were used to designate the start and stop of each generation (Figure 2.1). The date designated as the stop of one generation was assigned as the start of the following generation, because generations of onion maggot can overlap (Eckenrode et al., 1975). Distance from the field edge was treated as a quantitative variable (5 levels), while type of bordering habitat (2 levels = bordered or not bordered by woods) was treated as qualitative. A square-root transformation was used to stabilize the variance and normalize the data.

Data were analyzed as a randomized complete block design with split-split plots (Littell et al., 1996) replicated five times. Border type was the whole-plot factor, whereas distance from the field edge was the first sub-plot factor and sampling date within each generation was the second sub-plot factor within distance. Analysis was conducted using the PROC MIXED statement in SAS as it can accommodate unbalanced data (SAS Institute Inc., 2001). This method of analysis is homologous to a repeated measures analysis assuming compound symmetric covariance structure (Littell et al., 1996). This covariance structure assumes that all observations within a replication are equally correlated across time. This assumption was deemed appropriate in our case as the number of adults caught per trap per day should fluctuate synchronously across treatments as fly abundance and activity change according to onion maggot phenology (i.e., treatments within a replication should not diverge across time).

Figure 2.1 Mean (\pm SE) number of male (—■—) and female (—●—) onion maggot flies caught per sticky card per day for each sampling date in 2002 and 2003. Dotted vertical lines indicate estimated divisions between first- and second- and second- and third-generations of onion maggot, *Delia antiqua*, in New York.



Random error terms with a significance of $P \geq 0.1$ were dropped from the model. Their removal had no major effects on the results of analyses and generally improved model fit.

Separate analyses were conducted for each generation and gender of flies because both these factors interacted with treatment main effects. A preliminary analysis indicated that generation interacted with distance in both 2002 ($F = 4.84$, $df = 2, 130$; $P = 0.0094$) and 2003 ($F = 5.06$, $df = 2, 125$; $P = 0.007$). Further analyses indicated that fly gender interacted with border type in both the first (2002: $F = 6.82$, $df = 1, 84$; $P = 0.0107$; 2003: $F = 5.80$, $df = 1, 46$; $P = 0.0201$) and second generation (2002: $F = 30.45$, $df = 1, 84$; $P < 0.0001$; 2003: $F = 19.67$, $df = 1, 46$; $P < 0.0001$) in both years and during the third generation in 2002 ($F = 9.31$, $df = 1, 75$; $P = 0.0031$). Gender likewise interacted with distance for both the first (2002: $F = 7.33$, $df = 1, 84$; $P = 0.0082$; 2003: $F = 8.40$, $df = 1, 46$; $P = 0.0057$) and second generations (2002: $F = 6.43$, $df = 1, 84$; $P = 0.0131$; 2003: $F = 7.28$, $df = 1, 46$; $P = 0.0084$) in both years. Finally, the Bonferroni technique (Neter et al., 1996) was used to control experimentwise error for comparisons of fly activity between fields bordered and not bordered by woods on different dates while the Holm procedure as implemented by PROC MULTSTAT (SAS Institute Inc., 2002) was used to control error for pairwise comparisons of regression parameters across time (Experimentwise error was controlled at $\alpha = 0.05$).

The number of onion maggot flies caught per sticky card per day is represented in two ways for discussion within the text to ease interpretation of data. Firstly, where absolute numbers of flies are of concern, fly numbers are shown. Secondly, the percentage of the total number of flies caught within each farm at each distance x border type combination is presented where the relative number of flies being caught at different locations is of concern.

This made comparison easier across generations of onion maggot due to its emphasis on the relative rather than absolute number of flies occurring at each location.

First-generation egg numbers were averaged across subsamples within fields at each of the two distances from the field edge and quantified as the number of eggs laid per plant per day. Analysis for this study was conducted as described for adult activity with sampling date serving as the repeated measure. Distance from the edge was treated as a qualitative variable for this analysis, and PROC GLM was used in place of PROC MIXED as no observations were missing (SAS Institute Inc., 2001). A square-root transformation was used to stabilize the variance and normalize the data. Finally, the Tukey procedure as implemented by the LSMEANS statement of PROC GLM (SAS Institute Inc., 2001) was used to control experimentwise error at $\alpha = 0.05$ for pairwise comparisons of oviposition levels between treatment combinations.

Results

Patterns of adult activity within onion fields

More males were caught than females during both years of the study (Figure 2.1). Distinct peaks of flight activity were apparent for first and second-generation male onion maggot flies in both years. Peaks of first-generation female activity were apparent, while second-generation peaks were less distinct (Figure 2.1). First-generation males became active within onion fields approximately one week earlier than females in both 2002 and 2003, while this pattern was not obvious for later generations (Figure 2.1). In both years there was a sustained lull in activity within onion fields for both sexes after second-generation fly numbers declined (Figure 2.1). Although not obvious from data averaged over replicates, fly numbers increased in certain fields over the last two sampling dates in both years indicating onset of the third generation.

Numbers of male and female flies caught were not affected by a three-way interaction between distance, type of bordering habitat and sampling date in either 2002 or 2003 (Table 2.1 and 2.2). However, there were a number of significant two-way interactions between these variables during the first and second generations, but not during the third (Table 2.1 and 2.2). The remainder of the results focuses on a discussion of these interactions for each gender and generation of flies in both years or, when these interactions are not significant or important, describes the nature of each significant main effect.

The number of male and female onion maggot flies captured within onion fields was affected by a significant interaction between bordering habitat and distance from the field edge during the first generation of 2002 and 2003 (Table 2.1 and 2.2). On average, a larger percentage of male and female flies were caught in fields that bordered woods than in fields that did not in close proximity to field edges (Figure 2.2 and 2.3). However, percentages of male and female flies caught became more similar between field types at increased distances from the edge. Thus, the percentage of flies caught at a given location declined more dramatically with increasing distance away from the field edge in fields that bordered woods than in those not bordering woods. On average, 30% of males and 28% of females were caught closest to wooded edges while only 7% of both sexes were caught 184 m away from the same edges in 2002 (Figure 2.2). In 2003, an average of 30% of males and 27% of females were caught closest to wooded edges while 6 and 7% of males and females were caught 184 m away (Figure 2.3). A larger percentage of total fly numbers were consequently caught at traps closest to wooded edges than at any other location (Figure 2.2 and 2.3).

The number of onion maggot flies caught within fields was significantly affected by an interaction between type of bordering habitat and distance from the edge for second-generation males in 2002 (Table 2.1).

Table 2.1 Significance of effect of bordering habitat, distance from the field edge and sampling date on numbers of male and female first-, second- and third-generation onion maggot, *Delia antiqua*, flies caught per sticky card per day during 2002 in New York commercial onion fields

Sources of Variation	df	Males ^a		Females ^b	
		F	P	F	P
Generation One					
Border	1	22.19	0.0094	17.49	<0.0001
Distance	1	98.64	<0.0001	27.78	<0.0001
Date	5	63.28	<0.0001	43.01	<0.0001
Distance X border	1	16.99	<0.0001	7.52	0.0065
Border X date	5	2.50	0.0312	1.64	0.1497
Distance X date	5	2.53	0.0293	2.88	0.0150
Distance X border X date	5	1.63	0.1511	1.22	0.3010
Generation Two					
Border	1	4.06	0.0787	1.41	0.3004
Distance	1	48.20	<0.0001	19.78	<0.0001
Date	6	22.34	<0.0001	17.34	<0.0001
Distance X border	1	10.16	0.0016	1.43	0.2331
Border X date	6	1.24	0.2851	0.50	0.8112
Distance X date	6	1.14	0.3402	0.95	0.4560
Distance X border X date	6	0.07	0.9986	0.87	0.5206
Generation Three					
Border	1	2.69	0.1765	6.71	0.0605
Distance	1	15.58	0.0002	2.32	0.1315
Date	1	7.05	0.0095	13.51	0.0004
Distance X border	1	3.00	0.0869	0.92	0.3397
Border X date	1	0.04	0.8351	0.06	0.8028
Distance X date	1	0.25	0.6206	3.64	0.0600
Distance X border X date	1	0.19	0.6640	1.81	0.1828

^aMean-square errors for tests of treatment effects (Tested effect[s]: df, MSE) were as follows for first-generation males: Border: 4, 0.255 and all other effects: 264, 0.0847; second-generation males: Border: 8, 1.98 and all other effects: 313, 0.112; third-generation males: Border: 4, 0.349 and all other effects: 81, 0.0443.

^bMean-square errors for tests of treatment effects (Tested effect[s]: df, MSE) were as follows for first-generation females: all effects: 268, 0.0829; second-generation females: Border: 4, 0.547 and all other effects: 313, 0.0427; third-generation females: Border: 4, 0.0625 and all other effects: 81, 0.0188.

Table 2.2 Significance of effect of bordering habitat, distance from the field edge and sampling date on numbers of male and female first-, second- and third-generation onion maggot, *Delia antiqua*, flies caught per sticky card per day during 2003 in New York commercial onion fields

Sources of Variation	df	Males ^a		Females ^b	
		F	P	F	P
Generation One					
Border	1	7.79	0.0492	2.05	0.2253
Distance	1	81.34	<0.0001	62.78	<0.0001
Date	5	91.08	<0.0001	88.05	<0.0001
Distance X border	1	12.33	0.0012	4.03	0.0457
Border X date	5	2.61	0.0176	1.95	0.0725
Distance X date	5	3.70	0.0015	3.94	0.0008
Distance X border X date	5	1.27	0.2698	0.84	0.5370
Generation Two					
Border	1	7.03	0.0570	14.89	0.0178
Distance	1	49.20	<0.0001	32.89	<0.0001
Date	6	46.14	<0.0001	19.70	<0.0001
Distance X border	1	0.10	0.7483	0.61	0.4351
Border X date	6	6.28	<0.0001	2.21	0.0330
Distance X date	6	3.49	0.0013	3.18	0.0028
Distance X border X date	6	1.37	0.2189	0.68	0.6868
Generation Three					
Border	1	2.05	0.1961	2.36	0.1697
Distance	1	4.30	0.0422	3.04	0.0859
Date	1	11.85	0.0010	1.61	0.2081
Distance X border	1	1.42	0.2382	0.37	0.5436
Border X date	1	0.22	0.6391	0.08	0.7821
Distance X date	1	0.17	0.6814	1.63	0.2059
Distance X border X date	1	0.13	0.7169	0.13	0.7209

^aMean-square errors for tests of treatment effects (Tested effect[s]: df, MSE) were as follows for first-generation males: (Border: 4, 1.19), (Distance, Distance X border and Distance²: 37, 0.136) and (all other effects: 276, 0.0923); second-generation males: (Border: 4, 2.55), (Distance, Distance X border and Distance²: 37, 0.152) and (all other effects: 317, 0.0797); third-generation males: (Border: 7, 0.997) and (all other effects: 64, 0.0470).

^bMean-square errors for tests of treatment effects (Tested effect[s]: df, MSE) were as follows for first-generation females: (Border: 4, 1.16) and (all other effects: 313, 0.0523); second-generation females: (Border: 4, 0.119) and (all other effects: 354, 0.0460); third-generation females: (Border: 7, 0.0740) and (all other effects: 64, 0.0207).

Figure 2.2 Mean percentage of the total number of male and female first-, second- and third-generation onion maggot, *Delia antiqua*, flies captured in onion fields bordering or not bordering woods at varying distances from the field edge in New York in 2002. Filled symbols represent overall means while open symbols represent mean values for each replicate. Open and filled symbols of the same shape represent the same treatments.

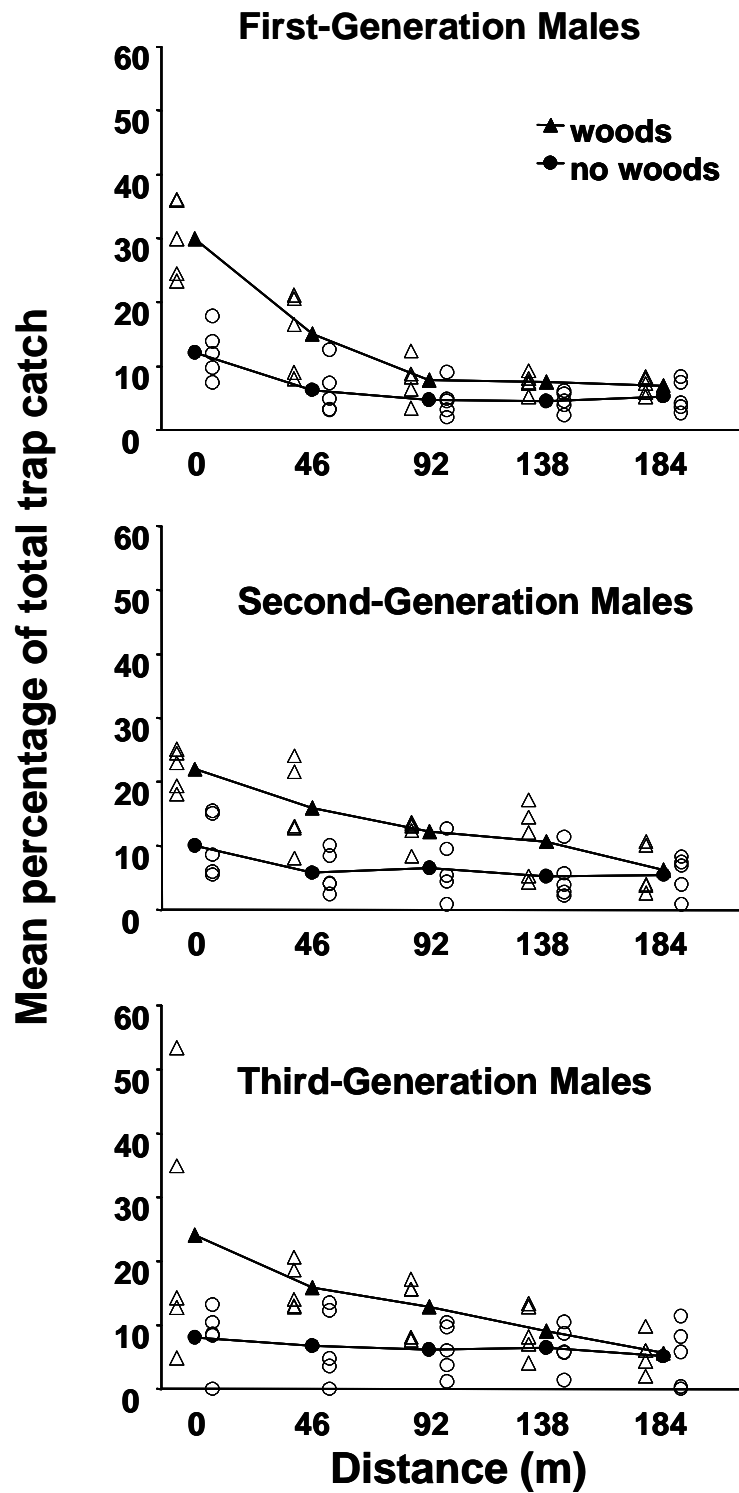


Figure 2.2 (Continued)

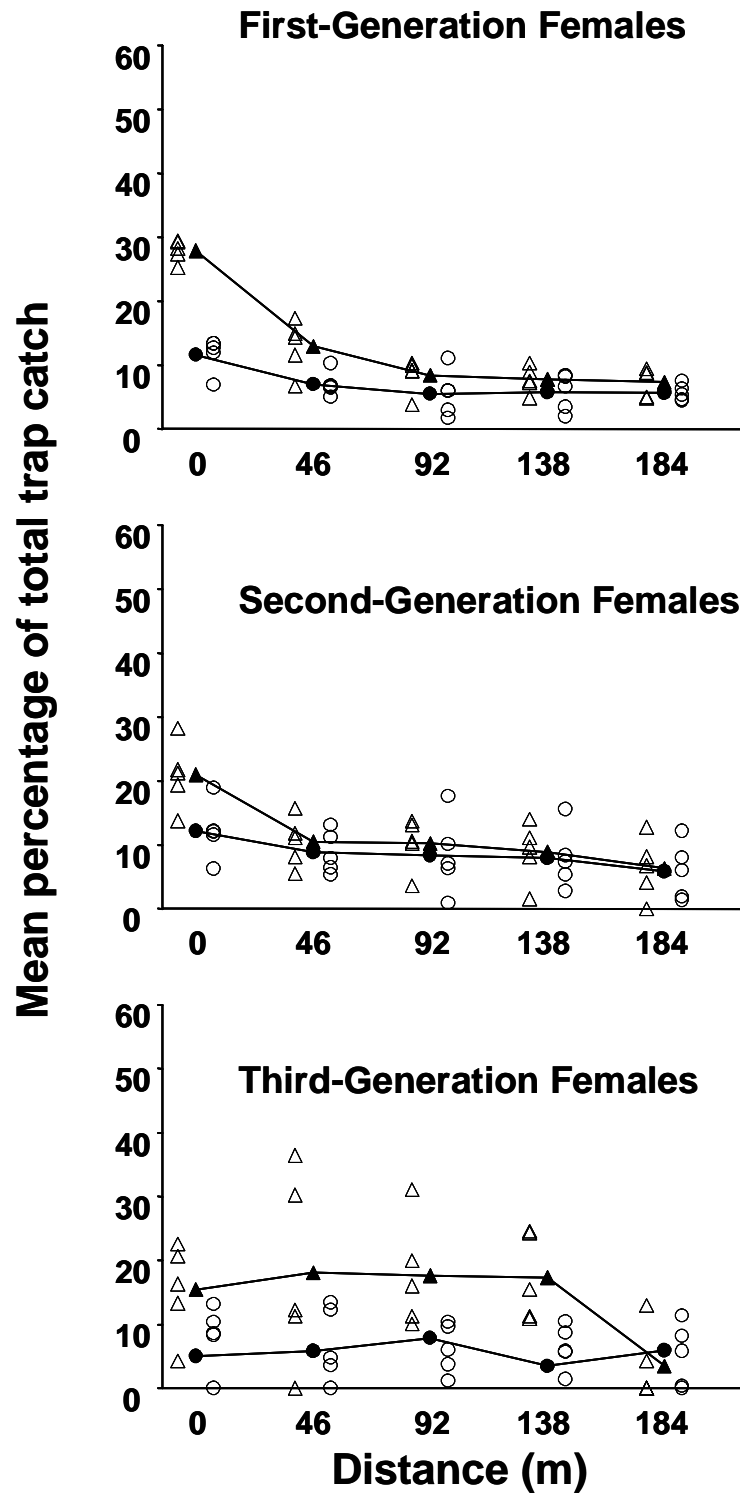


Figure 2.3 Mean percentage of the total number of male and female first-, second- and third-generation onion maggot, *Delia antiqua*, flies captured in onion fields bordering or not bordering woods at varying distances from the field edge in New York in 2003. Filled symbols represent overall means while open symbols represent mean values for each replicate. Open and filled symbols of the same shape represent the same treatments.

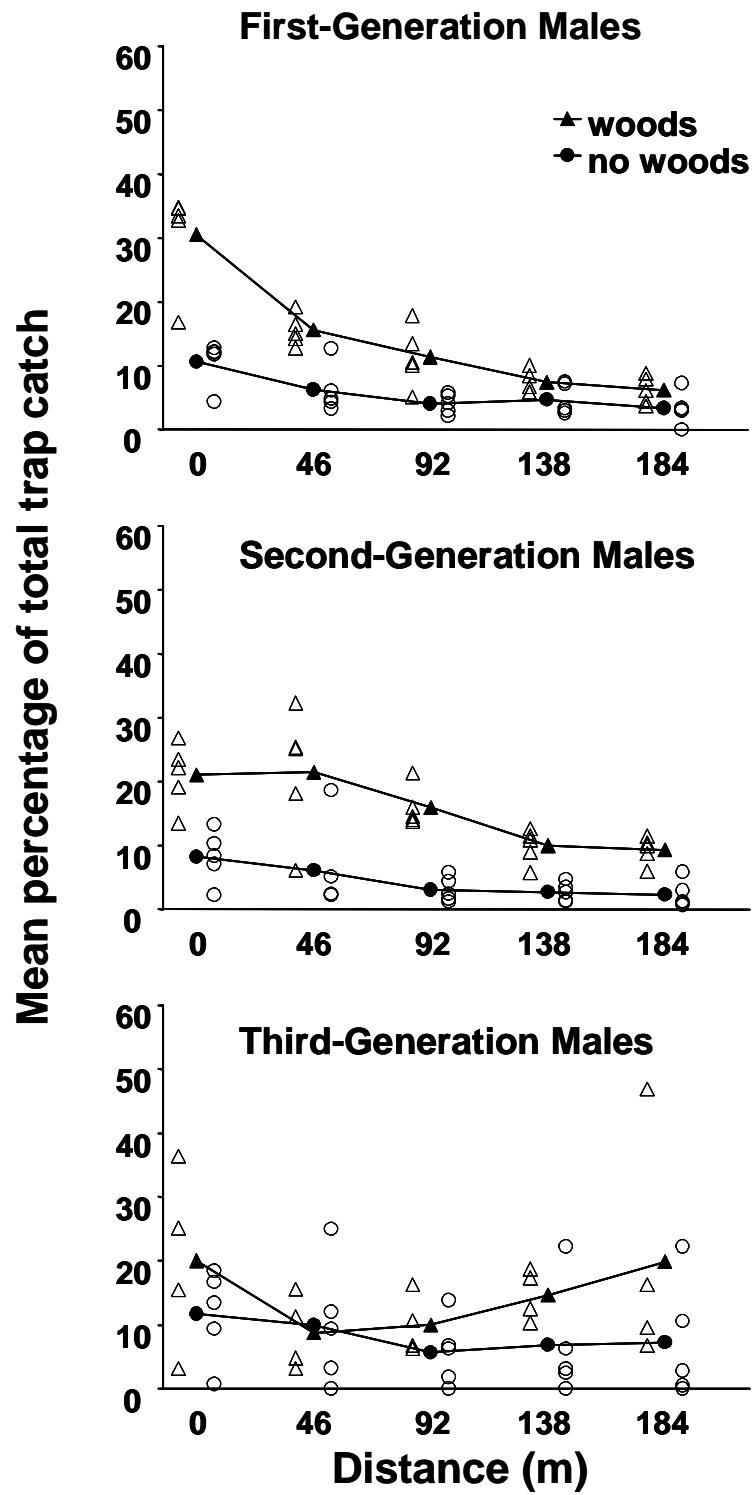
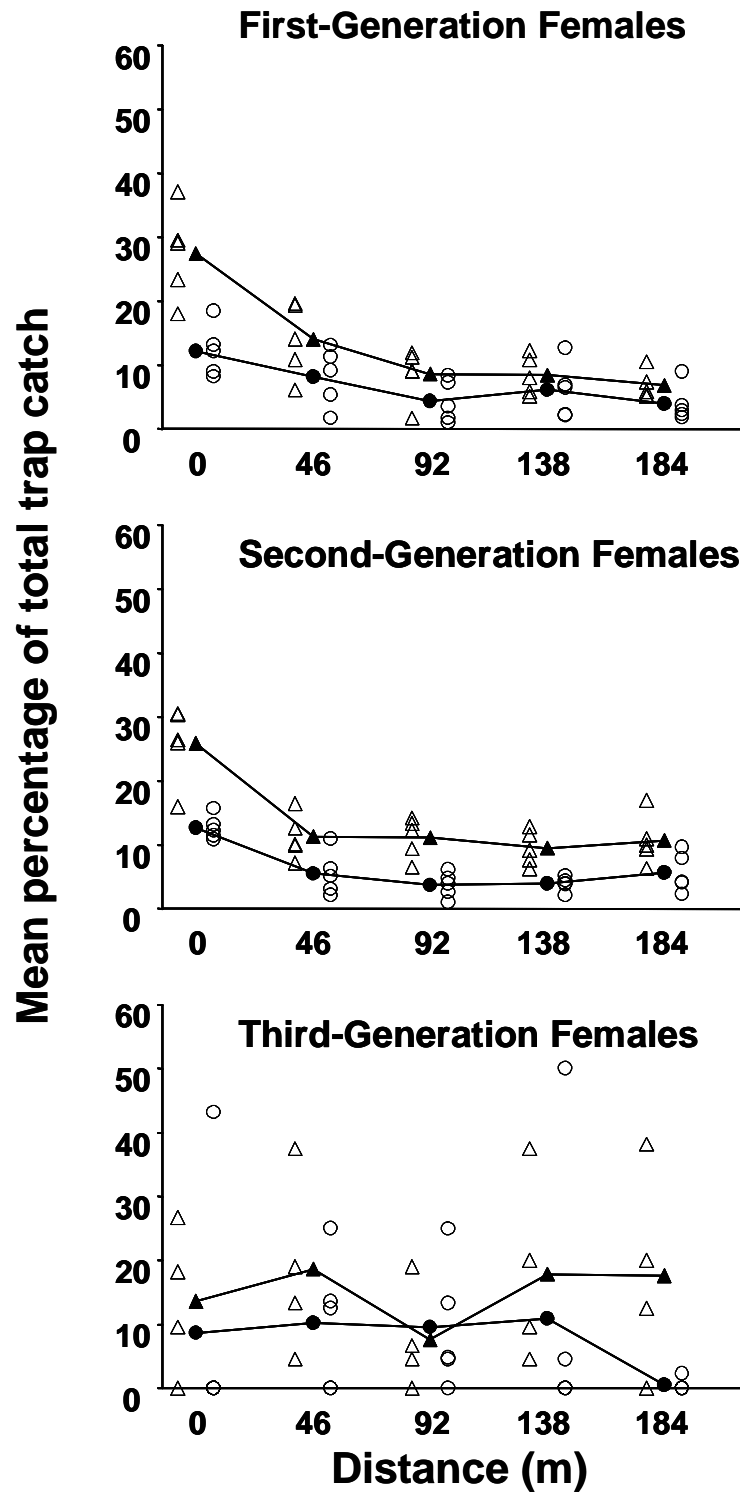


Figure 2.3 (Continued)



This interaction occurred because the number of flies caught was greater in fields bordering woods than in those that did not in close proximity to field edges, but became more similar between field types with increasing distance from the edge (Figure 2.2). Therefore the percentage of flies caught declined more rapidly with increased distance from the edge in fields bordering woods than in fields that did not, as it did for the first generation (Figure 2.2).

This interaction between border and distance did not significantly affect numbers of females caught during the second generation of 2002 or numbers caught of either sex of the second generation in 2003, but distance alone and (in certain cases) type of bordering habitat alone did (Table 2.1 and 2.2). In all these cases the number of flies caught by sticky cards declined significantly with increased distance away from field edges (Table 2.1 and 2.2, Figure 2.2 and 2.3). However, this decline was slightly less pronounced for males than that observed during the first generation. In particular, the number of males caught on sticky cards closest to wooded edges was slightly reduced in the second generation relative to the first in both years (Figure 2.2 and 2.3). In 2003, for example, an average of 30% of males were caught on sticky cards closest to wooded edges during the first generation, while only 21% were caught at this location during the second generation (Figure 2.2 and 2.3). The relationship between the percentage of flies caught at a given location and distance from the field edge was more similar for females between the first and second generations in both years (Figure 2.2 and 2.3).

Differences in the number of onion maggot flies caught between fields bordered and not bordered by woods were not significant for second-generation females in 2002 (Table 2.1), but were marginally significant for males and highly significant for females during the second generation of 2003 (Table 2.2).

These significant differences resulted from a larger percentage of flies being caught in fields bordering woods than in fields that did not (Figure 2.3).

There was no consistent, significant variation in numbers of third-generation onion maggot flies caught with increasing distance from the edge or type of bordering habitat across the two years of this study. Trap catch of males did decline significantly with distance in both years (Table 2.1 and 2.2), but this effect was not pronounced and was accompanied by a high degree of variability in the relative amounts of males caught at different distances in comparison with earlier generations (Figure 2.2, Figure 2.3). Third-generation females were almost entirely uniformly distributed across fields with respect to distance from edges (Figure 2.2, Figure 2.3). There was no significant variation in numbers of either sex caught between fields bordering different types of habitat during the third generation in either year (Table 2.1, Table 2.2).

In 2002 and 2003, the number of first- and second-generation male and female onion maggot flies caught by sticky cards was sometimes affected by two-way interactions between either type of bordering habitat or distance from the edge and sampling date (Table 2.1 and 2.2). These interactions with sampling date all resulted from the number of flies caught being more strongly associated with field type and distance from the edge at and after peaks of onion maggot fly activity. For example, the positive difference in numbers of first-generation flies caught between fields bordering and not bordering woods was more pronounced and significant for both sexes in 2002 at these times (Figure 2.4). The slope of the relationship between number of flies caught and distance from edges was accordingly steepest at these times for both sexes of the first generation in 2002, although significantly so only for females (Figure 2.5). These examples are illustrative of the nature of these two-way interactions wherever they occurred in our study.

Figure 2.4 Mean number of male and female onion maggot, *Delia antiqua*, flies caught per sticky card per day in commercial onion fields bordered and not bordered by woods for each sampling date within the first generation in New York in 2002. An asterisk signifies a significant difference on a certain sampling date ($P \leq 0.004$).

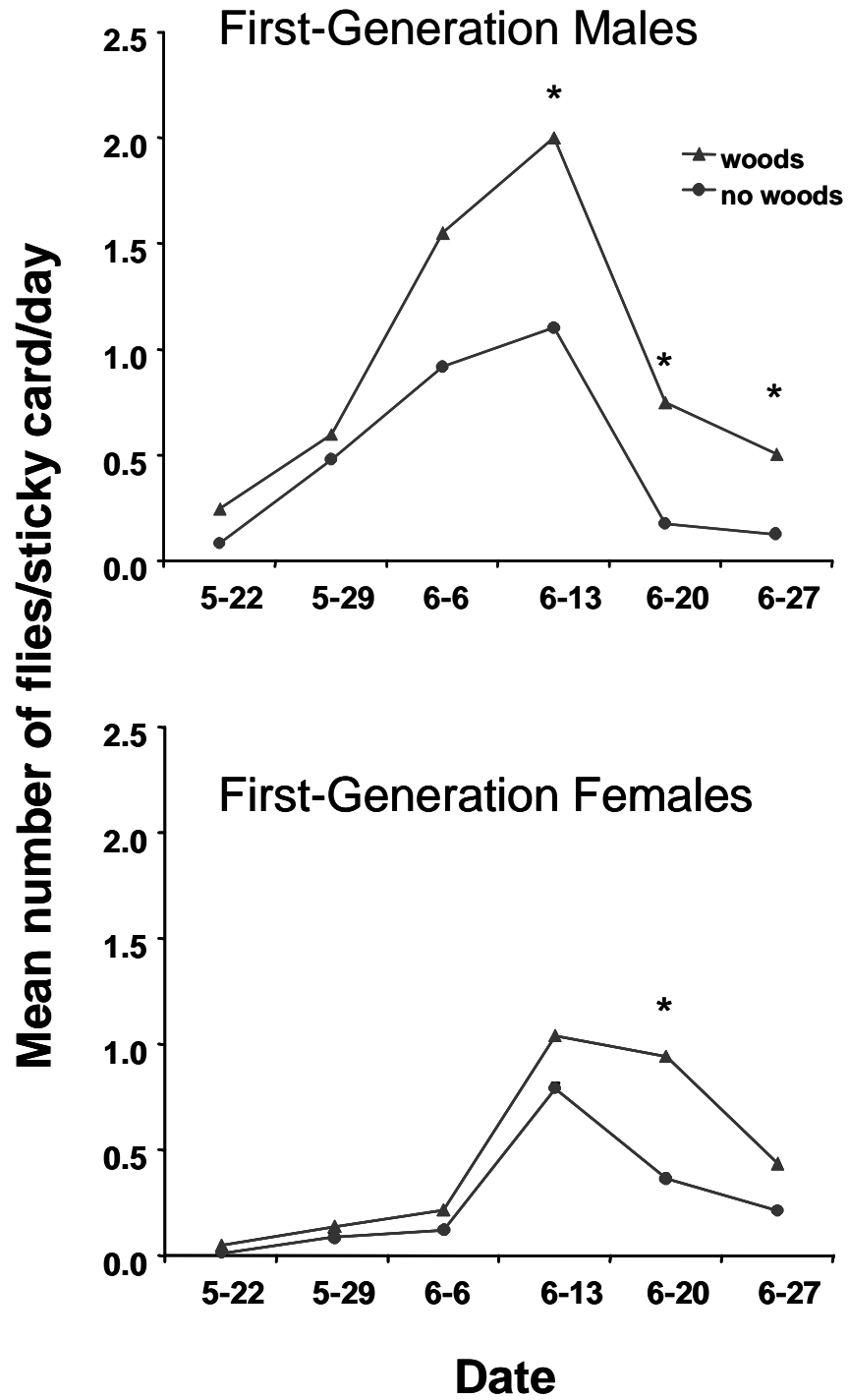
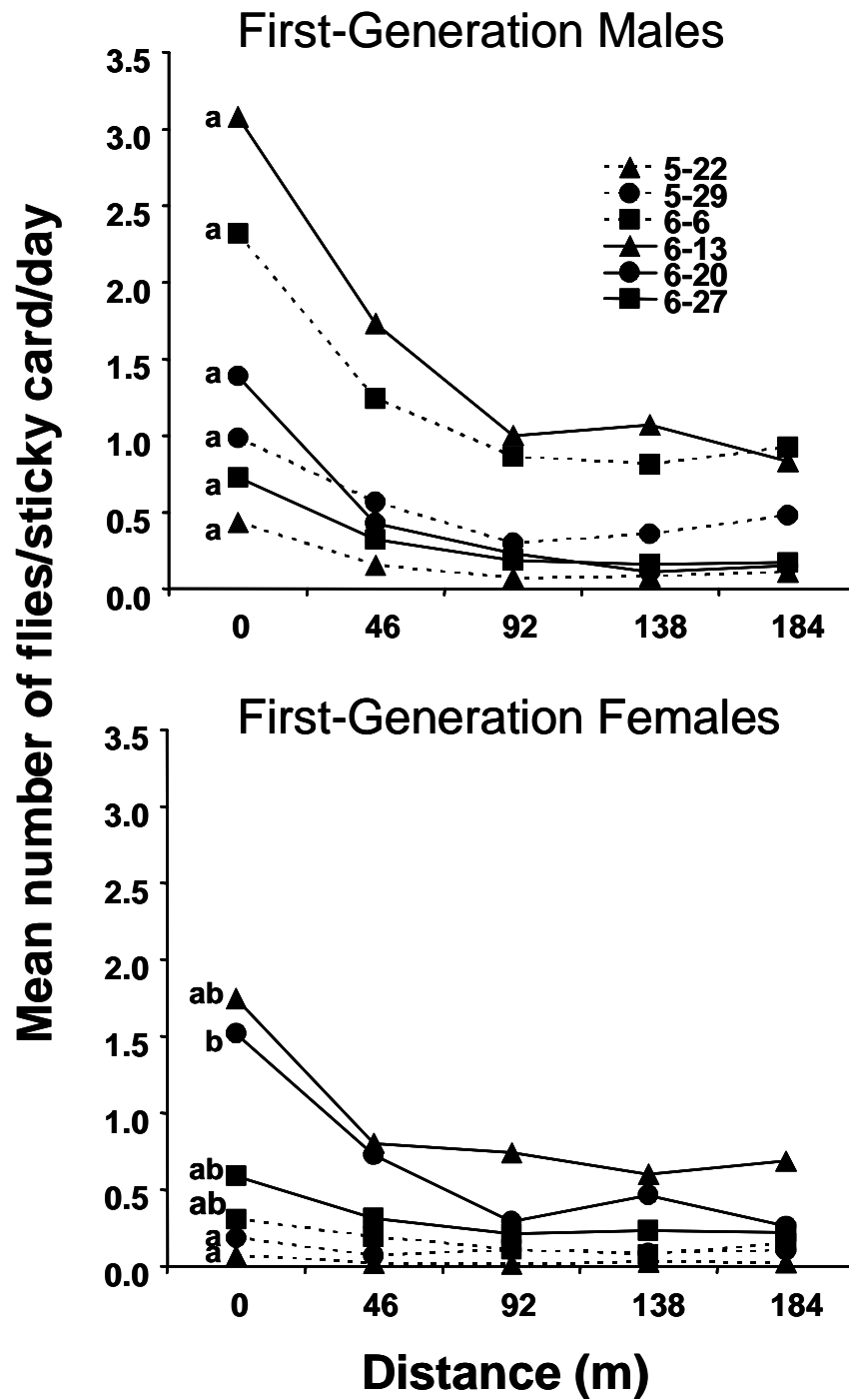


Figure 2.5 Mean number of male and female onion maggot, *Delia antiqua*, flies caught per sticky card per day at five distances from edges of commercial onion fields for each sampling date within the first-generation in New York in 2002. Sampling dates which did not have a significantly different ($P \geq 0.05$) slope for the sticky card catch-distance relationship are followed by the same letter.



Furthermore, these interactions are of limited biological importance because the relationship between type of bordering habitat or distance from the edge and the number of flies caught was very pronounced when onion maggot populations were high (i.e., when interactions of onion maggot with the crop would be of most importance). For these reasons other two-way interactions between sampling date and border or distance are not discussed.

Oviposition patterns of first-generation adults within onion fields

The number of eggs laid on sentinel onion plants was significantly affected by the sampling run of the experiment (Table 2.3). This resulted from more eggs being laid during the first run than in the second (Figure 2.6). The number of eggs laid on sentinel onion plants was not significantly affected by type of habitat bordering the onion field or distance from field edges (or their interactions) in either run of the experiment (Table 2.3, Figure 2.6).

Discussion

Onion maggot adult activity

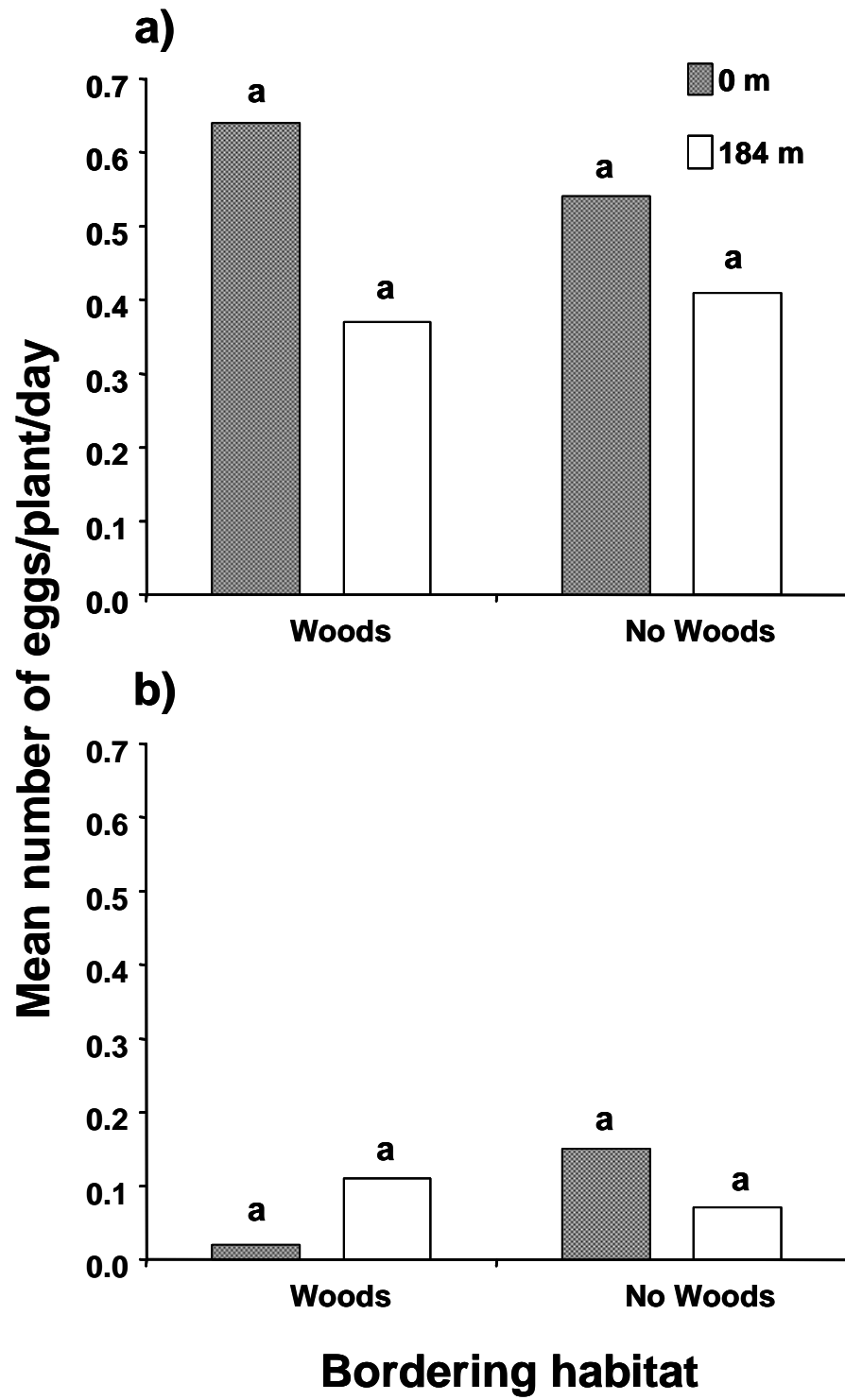
First and second-generation onion maggot flies of both sexes were most active along field edges during both years of our study. This edge effect was most pronounced in fields bordering woods during the first generation, indicating that the type of habitat bordering onion fields can potentially influence patterns of fly activity within fields. This influence of adjacent habitat on onion maggot adult activity within onion fields may explain why other researchers have observed an edge effect along certain field edges and not others (Finch et al., 1986a; Vernon et al., 1987; Vernon et al., 1989). Moreover, these edge effects were more evident during the flight of first-generation onion maggots than during subsequent generations.

Table 2.3. Significance of effect of bordering habitat, distance from the field edge and run of experiment and their interactions on number of onion maggot, *Delia antiqua*, eggs laid per sentinel onion plant during 2003 in New York commercial onion fields

Sources of Variation ^a	df	F	P
Border	1	0.36	0.5523
Distance	1	0.44	0.5121
Run	1	10.37	0.0041
Distance X border	1	0.73	0.4011
Border X run	1	0.02	0.9035
Distance X run	1	0.80	0.3807
Border X distance X run	1	0.06	0.8044

^aMean-square error for tests of treatment effects was (df, MSE): 21, 0.0880.

Figure 2.6 Mean number of onion maggot, *Delia antiqua*, eggs laid per plant per day on sentinel onion plants positioned at two distances from edges of commercial onion fields that either bordered or did not border woods in New York in 2003 for the first (a) and second (b) run of the experiment. Means with the same letter are not significantly different ($P \geq 0.05$).



Associations of onion maggot fly activity with distance from the edge and the type of bordering habitat were most pronounced in the first generation, but diminished as the season progressed. By the second generation differences in fly activity between fields bordering and not bordering woods became very variable and had disappeared by the third generation. Declines in flight activity with increased distance from field edges were also less pronounced for second than first generation males, and this edge effect was not consistently present for either sex during the third generation.

These changes in patterns of activity between generations suggest that some feature of the onion agroecosystem important to onion maggot flies was changing from generation to generation during this study. One very noticeable change was the growth of the onion crop. Onions present during the first peak of onion maggot flight activity in 2002, for example, were approximately 15-20 cm in height and had one to three leaves. By the beginning of the third generation plants were approximately 60 cm in height and had 12-13 leaves. There were accordingly significant changes in the amount of shade and shelter available for insects within onion fields during the growing season.

Onion maggot flight activity within onion fields shows distinct peaks in the early morning and late afternoon/early evening (Finch et al., 1986a); few flies are caught within fields during the middle of the day. Oviposition in the laboratory displays a similar periodicity with peak oviposition occurring in the evening (Havukkala & Miller, 1987). These patterns suggest that flies are not active within fields during midday, possibly because they are seeking shelter from the high temperatures that often occur on muck soils during sunny days. Muck soil is black and absorbs heat during sunny days. Soil surfaces can therefore become very hot in June and July; surface temperatures can reach 60°C (Havukkala & Miller, 1987).

In cage studies, Finch (1986a) accordingly found that flies sought shelter in vegetation or soil cracks during midday when temperatures were highest.

Flies may be relatively inactive and remain in sheltered areas during the heat of the day when environmental conditions are harshest. Early in the season when shelter within onion fields is sparse, flies may seek shelter in the vegetation surrounding fields during midday to escape harsh environmental conditions. Thus a large percentage of flies will retreat to field margins during these times and will return to fields when environmental conditions are more moderate during mornings and evenings. This may result in an edge effect in onion maggot flight activity occurring early in the season. As the season progresses and onions grow, the environment within onion fields may become more moderate and flies may have less need to seek shelter along field borders. As fewer flies seek shelter here edge effects would diminish. Wooded habitat surrounding fields may provide superior shelter when environmental conditions are harsh, resulting in edge effects being most pronounced adjacent to these areas. Wooded areas may also serve as windbreaks early in the season when windspeeds in New York onion fields can be quite high (BPW, personal observation). When shelter in surrounding habitat is less important, associations between fly activity and type of bordering habitat may break down, as was observed in our study.

Hawkes (1972) found that activity of cabbage maggot flies, *D. radicum* (L.), a congener of onion maggot, displays similar edge effects (Hawkes, 1972). Hawkes (1972) also found that trap catch decreased in bordering hedgerows while it increased within fields in early afternoon (12:30 to 14:30); this pattern reversed later in the day (14:30 to 20:00). Cabbage maggot may move between bordering vegetation and the crop on a daily basis as hypothesized for onion maggot (Finch et al., 1986a). The carrot root fly, *Psila rosae* (F.) (Diptera: Psilidae), and the pepper maggot,

Zonosemata electa (Say) (Diptera: Tephritidae), also move between adjacent vegetation and fields and display similar edge effects in flight activity (Petherbridge & Wright, 1943; Judd et al., 1985; Boucher et al., 2001). This suggests that other crop pests which divide their activity between the crop and adjacent habitat may display such edge effects, and lends support to the hypothesis (Finch et al., 1986a) that onion maggot also engages in daily movement into and out of the crop.

Hawkes (1972) found that in the laboratory most *D. radicum* feeding takes place early in the morning. In the field this is the period when they are supposedly most active within vegetation bordering fields. Bordering vegetation may thus be utilized as a food source by cabbage maggot in addition to or in place of acting as shelter. Onion maggot females must feed in order to produce eggs (McLeod, 1964). Male longevity also shows a five-fold increase when they are allowed access to food (McDonald & Borden, 1996). Feeding is thus important for adult onion maggots and they may obtain most of their food from vegetation surrounding fields. Flies can often be observed in these locations feeding at flowers (Baker, 1928). Thus, surrounding vegetation may act as a food resource for onion maggot in addition to serving as shelter.

However, the idea that the intensity of edge effects in onion maggot flight activity is linked with the physical structure of crop habitat (and not food availability in different locations) is supported by the fact that third generation trap catch in bordering vegetation and field interiors is relatively similar before harvest, while it is greater in surrounding vegetation after plants are harvested (Carruthers, 1981). If our study had extended beyond onion harvest we may have found a similar reoccurrence in the observed edge effect during the third generation. It is likely, however, that onion maggot flies utilize vegetation that surrounds onion fields to obtain a combination of resources.

The relative abundance of these resources may vary between onion fields and the surrounding habitat with time, resulting in corresponding changes in edge effects.

In contrast to adult flight activity, oviposition showed no consistent variation between fields bordering and not bordering woods and between different distances within these fields (Figure 2.6). This dichotomy between patterns of adult activity and oviposition may exist for a number of reasons. Hawke (1972) found that gravid cabbage maggot females were more uniformly distributed across distances from an adjoining hedgerow than non-gravid females, which were most active next to the hedgerow. Our counts of female onion maggot sticky card-catch did not distinguish between ovipositing and non-ovipositing flies. Ovipositing onion maggot flies may move much farther from the edge into fields than non-ovipositing flies, resulting in eggs being laid at most distances from the edge. Our study lacked the resolution to determine if this is the case.

Secondly, it cannot be ruled out that our yellow sticky cards were more attractive to non-ovipositing than ovipositing females. Judd & Whitfield (1997), for example, found that sticky cards baited with enzymatic yeast hydrolysate were more attractive to sexually immature females than dipropyl-disulfide-baited traps, while traps baited with dipropyl-disulfide were most attractive to mature females. Enzymatic yeast hydrolysate is a compound associated with food (Miller & Haarer, 1981) while dipropyl-disulfide is a compound associated with onions (Brewster, 1984). This suggests that ovipositing females do little feeding and focus their efforts on finding hosts for oviposition. If the attractive stimuli associated with yellow sticky cards represent a food source, they may thus be less attractive to ovipositing than non-ovipositing flies. Female *D. radicum* feeds very little during periods of oviposition (Hawkes 1972).

Implications for onion maggot management

Our results suggest that it may be possible to limit application of insecticides targeting adult onion maggot to field edges during the first and second generations. It might be especially appropriate to spot treat those field edges bordering woods. The fact that the patterns in adult activity noted above are most pronounced during the first generation is promising, since this generation causes the majority of maggot damage to onion (Loosjes, 1976). While there was some variation in these patterns across time within a generation, they were pronounced during peaks of fly activity when control would be of most concern (Figure 2.4, Figure 2.5).

However, the maximum difference in fly activity between traps along edges and traps farthest away was only three-fold (Figure 2.2, Figure 2.3). Thus, while our data suggest that spot treating field edges merits further testing, it also suggests caution in the implementation of such an approach since some proportion of the population may be located away from edges when treatments are applied. This is true regardless of the time of day for cabbage maggot (Hawke, 1972), suggesting that even if treatments of field edges are applied when flies are most active here some may still escape control. This would be of major concern when insecticides must contact adult onion maggot flies to be effective, as was shown to be the case for foliar sprays of parathion (Finch et al., 1986a).

A sprayable bait containing spinosad that has been recently developed for Tephritid flies (GF-120 Fruit Fly Bait, DowAgrosciences, Indianapolis, IN) has also been shown to kill onion maggot flies in preliminary laboratory trials (Werling & Nault, unpublished). Sprayable baits could be applied in a spot treatment for onion maggot along wooded field edges. These baits would avoid the problem associated with foliar sprays, since they do not rely on direct contact with pests to be effective and are formulated to last long periods.

Most flies would encounter these treatments along field edges as they move in and out of fields on a daily basis, regardless of where flies were during application.

While our data suggests that spot treatments may have potential for control of adults, this was not the case for controls targeting immature stages of onion maggot. The fact that similar numbers of eggs were laid at both sampled distances from field edges (Figure 2.6) suggests that controls targeting larvae should be applied on a field-wide basis, as they are currently.

Even though differences in fly activity between edges and centers of fields are not overwhelming, they still may be exploitable for control using certain non-chemical methods. It may be possible, for example, to arrest first-generation onion maggot flies along field edges before they enter the crop interior. In essence this would amount to enhancing an already present edge effect by introducing some arrestant factor along field edges. This principle has been exploited in developing a trap-cropping strategy to protect bell peppers from infestation by pepper maggot, *Z. electa* (Say) (Diptera: Tephritidae) (Boucher et al., 2003). An edge effect in oviposition along bordering vegetation is observed for this fly. This edge effect is increased when a trap crop is introduced in these areas (Boucher et al., 2003). Pepper maggot apparently takes refuge in vegetation surrounding fields when not on host plants (Boucher et al., 2001) and moves back into fields to oviposit. This situation may thus be analogous to the one existing for onion maggot.

Trap cropping has long been considered as a potential method of control for onion maggot (Dudley, 1925). While volunteer onions have been suggested as a trap crop in the past (Mowry, 1993), it may be possible to use transplanted onions instead. While most New York onions are grown from seed, acreage of transplanted onions has been increasing in recent years (BAN, personal observation). A small portion of fields (usually next to edges) is often transplanted with onions with the remainder being

planted from seed. Transplant-size plants are preferred for oviposition over plants the size of seeded onions (Werling & Nault, unpublished), suggesting transplants have some potential for use as a trap crop. Placing transplants near field edges may arrest flies before they move into the field. Spraying these plants with insecticidal bait (see above) may also be an effective complement to this technique.

Documenting spatial and temporal patterns of insect pest activity within crops adds to our basic understanding of the ecology of specific crop pests and crop pest ecology in general. In certain instances these patterns may be exploitable for control using existing management strategies. If not, they may provide a basis for the development of new control strategies. Thus, gaining knowledge of these patterns is an important step in developing sustainable management practices.

References

- Baker, AD (1928) The habits of the onion maggot flies (*Hylemya antiqua* Meigen). Annual Report of the Entomological Society of Ontario 58: 61-67.
- Boucher TJ, Ashley RA, Adams Jr. RG & Morris TF (2001) Effect of trap position, habitat, and height on the capture of pepper maggot flies (Diptera: Tephritidae). Journal of Economic Entomology 94: 455-461.
- Boucher TJ, Ashley R, Durgy R, Sciabarrasi M & Calderwood W (2003) Managing the pepper maggot (Diptera: Tephritidae) using perimeter trap cropping. Journal of Economic Entomology 96: 420-432.
- Brewster JL (1994) Onions and Other Vegetable Alliums. CAB International, Wallingford, UK.
- Brooks AR (1949) The identification of the commoner root maggots of garden crops in Canada. Mimeographed pamphlet. Department of Agriculture, Division of Entomology, Canada.
- Carruthers, RI (1981) The Biology and Ecology of *Entomophthora muscae* (Cohn) in the Onion Agroecosystem. PhD Dissertation. Michigan State University, MI, USA.
- Cowles RS & Miller JR (1992) Diverting *Delia antiqua* (Diptera: Anthomyiidae) oviposition with cull onions: Field studies on planting depth and a greenhouse test of the stimulo-deterrent concept. Environmental Entomology 21: 453-460.
- Dudley Jr. JE (1925). Cull onions as a trap crop for the onion maggot. Journal of Economic Entomology 18: 639.
- Eckenrode CJ (1985) Onion maggot damage increasing: Pesticide resistance calls for integrated pest controls. American Vegetable Grower June: 10-12.
- Eckenrode CJ (1988) *Delia antiqua* (Meigen): An increasing threat in North America. In: Narkiewicz-Jodko J & Nawrocka B (eds), International Symposium on Diptera Pests in Vegetable Crops. International Society of Horticultural Science, Skierniowice, Poland, pp. 27-30.
- Eckenrode CJ & Nyrop JP (1995) Onion maggot management in New York, Michigan and Wisconsin. New York's Food & Life Sciences Bulletin, no. 144. Cornell University, NY, USA.
- Eckenrode CJ, Vea EV & Stone KW (1975) Population trends of onion maggots correlated with air thermal unit accumulations. Environmental Entomology 4: 785-789.

Finch S, Cadoux ME, Eckenrode CJ & Spittler TD (1986b) Appraisal of current strategies for controlling onion maggot (Diptera: Anthomyiidae) in New York state. *Journal of Economic Entomology* 79: 736-740.

Finch S, Eckenrode CJ & Cadoux ME (1986a) Behavior of onion maggot (Diptera: Anthomyiidae) in commercial onion fields treated regularly with parathion sprays. *Journal of Economic Entomology* 79: 107-113.

Hausmann SM & Miller JR (1989) Ovipositional preference and larval survival of the onion maggot (Diptera: Anthomyiidae) as influenced by previous maggot feeding. *Journal of Economic Entomology* 82: 426-429.

Havukkala IJ & Miller JR (1987) Daily periodicity in the ovipositional behavior of the onion fly *Delia antiqua* (Diptera: Anthomyiidae.) *Environmental Entomology* 16: 41-44.

Havukkala IJ, Harris MO & Miller JR (1992) Onion fly egg distribution in soil: a new sampling method and the effect of two granular insecticides. *Entomologia Experimentalis et Applicata* 63: 283-289.

Hawkes C (1972) The diurnal periodicity and cycle of behaviour of the adult cabbage root fly (*Erioischia brassicae*). *Annals of Applied Biology* 70: 109-118.

Judd GJR, Vernon RS & Borden JH (1985) Monitoring program for *Psila rosae* (F.) (Diptera: Psilidae) in southwestern British Columbia. *Journal of Economic Entomology* 78: 471-476.

Judd GJR & Whitfield GH (1997) Visual and olfactory behaviour of *Delia antiqua* (Diptera: Anthomyiidae) in relation to time of day and ovarian development. *European Journal of Entomology* 94: 199-209.

Littell RC, Milliken GA, Stroup WW & Wolfinger RD (1996) *Sas System for Mixed Models*. SAS Institute Inc., NC, USA.

Liu HJ, McEwen FL & Ritcey G (1982) Forecasting events in the life cycle of the onion maggot, *Hylemya antiqua* (Diptera: Anthomyiidae): Application to control schemes. *Environmental Entomology* 11: 751-755.

Loosjes, M (1976) *Ecology and Genetic Control of the Onion Fly, Delia antiqua* (Meig.). Center for Agricultural Publishing and Documentation, Wageningen, The Netherlands.

- McDonald RS & Borden JH (1996) Dietary constraints on sexual activity, mating success, and survivorship of male *Delia antiqua*. *Entomologia Experimentalis et Applicata* 81: 243-250.
- McLeod, DGR (1964) Nutrition and feeding behavior of the adult onion maggot, *Hylemya antiqua*. *Journal of Economic Entomology* 57: 845-847.
- Miller JR & Haarer BK (1981) Yeast and corn hydrolysates and other nutritious materials as attractants for onion and seed flies. *Journal of Chemical Ecology* 7: 555-562.
- Mowry TM (1993) Ovipositional patterns and larval movement of *Delia antiqua* (Diptera: Anthomyiidae) on sprouted bulb and seedling onions. *Journal of Economic Entomology* 86: 1440-1445.
- Neter J, Kutner M, Nachtsheim CJ & Wasserman W (1996) *Applied Linear Statistical Models*. 4th edn. WCB/McGraw-Hill, MA, USA.
- Petherbridge FR & Wright DW (1943) Further investigations on the biology and control of the carrot fly (*Psila rosae* F.). *Annals of Applied Biology* 30: 348-358.
- SAS Institute Inc. (2001) Ver. 8.2. SAS Institute Inc., Cary, NC, USA.
- Sciaretta A, Trematerra P & Baumgartner J (2001) Geostatistical analysis of *Cydia funebrana* (Lepidoptera: Tortricidae) pheromone trap catches at two spatial scales. *American Entomologist* 47: 174-184.
- Shukla RP & Tandon PL (1985) Bioecology and management of the mango weevil *Sternochetus mangiferae* (Coleoptera: Curculionidae). *International Journal of Tropical Agriculture* 3: 293-303.
- Slosser JE, Boring III EP, Price JR & Puterka GJ (1987) Influence of field margins on densities of cotton fruit and on boll weevils and their damage during late season. *Southwestern Entomologist* 12: 253-258.
- Tandon PL & Shukla RP (1989) Spot application of insecticides for the management of mango stone weevil, *Sternochetus mangiferae* (Fabr.). *Acta Horticulturae* 231: 571-574.
- Taylor AG, Eckenrode CJ & Straub RW (2001) Seed coating technologies and treatments for onion: Challenges and progress. *HortScience* 36: 199-205.
- Vernon RS, Hall JW, Judd GJR & Bartel DL (1989) Improved monitoring program for *Delia antiqua* (Diptera: Anthomyiidae). *Journal of Economic Entomology* 82: 251-258.

Vernon RS, Judd GJR & Borden JH (1987) Commercial monitoring program for the onion fly, *Delia antiqua* (Meigen) (Diptera: Anthomyiidae) in southwestern British Columbia. *Crop Protection* 6: 304-312.

Whitfield GH (1981) Spatial and Temporal Population Analysis of the Onion Maggot (*Hylemya antiqua* (Meigen)), in Michigan. PhD Dissertation. Michigan State University, MI, USA.

Yildirim E & Hoy CW (2003) Interaction between cyromazine and the entomopathogenic nematode *Heterorhabditis bacteriophora* Poinar "GPS11" for control of onion maggot, *Delia antiqua* (Meigen). *Crop Protection* 22: 923-927.

CHAPTER THREE

Effects of onion plant age on onion maggot damage in the field and laboratory

Introduction

Onion maggot, *Delia antiqua* (Diptera: Anthomyiidae) (Meigen), is the principal insect pest of onion, *Allium cepa* L., throughout the temperate northern hemisphere (Loosjes, 1976). Onion maggot damages the onion crop when larvae feed on the portion of the plant below the soil surface (Hoffmann et al., 1996). There are three generations of onion maggot each year in New York, the last of which overwinters as a pupa in the soil within onion fields (Hoffmann et al., 1996). Of the three generations of maggots, the first is the most damaging to onion (Loosjes, 1976). Control efforts are consequently focused on preventing damage caused by first-generation larvae.

Control of onion maggot currently relies almost entirely on insecticides (Eckenrode & Nyrop, 1995). However, insecticide resistance is a chronic problem in managing onion maggot (Loosjes, 1976; Ellis & Eckenrode, 1979; Harris et al., 1982; Walters & Eckenrode, 1996). Furthermore, while control is currently adequate in New York, it is based largely on only two insecticides, chlorpyrifos and cyromazine (Taylor et al., 2001). Many populations have already developed resistance to chlorpyrifos (Eckenrode, 1985; Nault, unpublished), leaving cyromazine as the only viable option for control of onion maggot in these instances. Developing cultural controls for onion maggot in such situations is particularly important because they would not only reduce the overall size of the population, but would kill insecticide-resistant genotypes.

Delaying planting as long as possible in the spring has been recommended, but never evaluated, as a method of cultural control for onion maggot (Doane & Chapman, 1952).

The goal behind this strategy is to allow the onion crop to escape infestation by first-generation onion maggots by reducing the time plants are exposed to oviposition by spring-emerging flies.

Onions may become more resistant to onion maggot attack as they grow and mature. For example in New York, Finch et al. (1986) found that 37% of onion maggot eggs placed on plants taken from fields on 19 July survived to pupation, while no pupae were produced on older plants removed from these fields on 24 August. In contrast to the recommendation of planting late to avoid onion maggot attack (Doane & Chapman 1952), these results suggest that it is preferable for growers to plant onions early in the season so that onions are as old as possible, and thus maximally resistant to onion maggot, by the time of first maggot attack. Yet, damage by onion maggot typically occurs more commonly in early-planted onion fields than in late-planted ones. Thus, some factor must be causing the inherent resistance of older plants to onion maggot to break down. Onion maggot lays more eggs on larger plants when offered a choice between these and smaller plants (Harris et al., 1987). Early-planted onions will be larger than late-planted ones by the first peak of onion maggot oviposition; densities of first-generation onion maggot eggs may therefore be greater on early- than late-planted onions. The increased resistance of older, earlier-planted onions as compared with younger, later-planted ones may then be overcome by high densities of invading larvae. We hypothesize that damage by onion maggot can be reduced by planting onions later in the spring, primarily because onion maggots are not likely to deposit their eggs on young plants.

The overall goal of research detailed below was to examine late planting of onion crops as a cultural control for onion maggot. This tactic was evaluated in the field by quantifying levels of onion maggot damage in three sequential plantings of onion.

To help identify the factors responsible for differences in levels of onion maggot damage observed in these plantings, we evaluated how plant age affects resistance to onion maggot damage at a variety of egg densities in the laboratory. Furthermore, we evaluated ovipositional preference by onion maggot for different aged onion plants in the laboratory.

Materials and Methods

Effect of planting date on onion maggot damage levels

This experiment was conducted in a commercial onion field in Yates County, NY in 2003. The soil type that onions are grown on in this area is Carlisle muck (Pearson & Cline, 1958). Three plantings of onion (var. 'Millenium') were staggered three weeks apart, yielding an early, middle and late planting (= three planting date treatment levels). Early plantings were seeded on 16 April, which is the time when most of the earliest commercial plantings occur in this county, while middle and late plantings occurred on 6 and 28 May, respectively. Each plot consisted of 7.62 m of row separated from other rows by approximately 38 cm. Treatments were arranged in a randomized complete block design replicated six times, with replicates positioned perpendicular to the field edge.

A hand-pushed cone seeder was used to plant plots at a rate of 30 seeds per meter of row (= 229 seeds per plot). All seeds were treated with the fungicides thiram and vitavax (Pro-Gro[®], Gustafson, Plano, TX) at 20 g (AI)/kg of seed. A drench treatment of the fungicide mancozeb (Dithane[®] F-45, Dow AgroSciences, Indianapolis, IN) was also applied at planting at a rate of 5.6 liters per hectare.

Baseline stand counts were taken on 20 May and 11 June. Baseline counts for each plot were adjusted by subtracting the number of plants that died due to causes other than onion maggot during the season, yielding an approximation of the number

of plants that would have survived if onion maggot damage had been nil (this measure was labeled the “final stand count”). The number of plants dying due to onion maggot feeding were recorded on a weekly basis after the first sign of maggot damage (3 June) until one week after the peak of the second flight of onion maggot (22 July). Larvae produced by third-generation flies cause minimal amounts of damage to onion (Liu et al., 1982). Seedlings containing maggot larvae or those clearly damaged by maggots (but larva not present) were recorded as damaged and then removed from the plot. The total number of seedlings lost by each date due to onion maggot was divided by the final stand count to obtain a cumulative measure of the percentage of plants damaged by onion maggot for each plot.

Activity of female onion maggot flies was also assessed on a weekly basis beginning at the estimated start of first-generation emergence (13 May). Twenty, non-baited 15 cm x 15 cm yellow sticky cards (Olson Products, Medina, OH) were clamped to stakes at an initial height of 13 cm above the ground. Thereafter height was adjusted to keep card tops level with the onion canopy. Five of these sticky cards were placed 46 m apart in each of four rows adjacent to the planting date trial. Cards were taken back to the lab and the number of female onion maggot flies per card was recorded. Flies were identified and sexed according to the key of Brooks (1971). These data enabled us to relate incidence of plant damage to female onion maggot phenology.

Mean cumulative percent damage by onion maggot through time was analyzed as a repeated measures design using the REPEATED statement in PROC GLM (SAS Institute Inc., 2001), with sampling date serving as the repeated measure. A square root ($x + 0.0001$) transformation was used to stabilize the variance and ensure normality for cumulative percent damage data.

Finally, LSD mean separation as implemented by the MEANS statement in PROC GLM was used to determine treatment differences for each sampling date with an experimentwise error rate of $\alpha = 0.05$ (SAS Institute Inc., 2001).

Test insects used in laboratory experiments

All onion maggot eggs and flies used in the laboratory experiments described below were obtained from colonies maintained in a growth chamber (16L: 8D, 21°C, 60%rh) at Cornell University's New York State Agricultural Experiment Station (NYSAES) in Geneva, NY. Eggs for the plant age/egg density experiment were obtained from a colony started from larvae collected the previous year from fields in Yates County, New York. Flies were allowed to oviposit in a dish containing sand and a peeled onion; eggs were then floated out of the sand using water.

Flies used in ovipositional preference tests were taken from a mixed-age colony started from Michigan onion maggot populations and were removed from the field by several generations. In a previous study, ovipositional preferences of these flies were similar to those of flies taken more recently from New York fields (Werling & Nault, unpublished).

Effect of plant age and egg density on onion maggot damage levels

This experiment was conducted at NYSAES. Onion maggot damage to onion plants (var. 'Millenium') was evaluated after plants were infested at varying ages with varying densities of eggs. A single onion seed treated with the fungicide Pro-Gro[®] (20 g (AI)/kg of seed) was planted in a 5.08 cm x 5.08 cm plastic pot (= experimental unit) filled with muck soil from a nearby commercial farm. Plants were maintained in the greenhouse (16L: 8D) and watered and fertilized as needed. When seedlings were two, four, six, and eight weeks old they were infested one time with either two, five or ten eggs per plant. These plants were subsequently maintained in a growth chamber for the duration of the experiment (16L: 8D, 21°C, 60%rh). The experiment was

designed as a completely randomized four (seedling age) x three (egg density) factorial with 20 replications. Each plant was recorded as either damaged or undamaged after nine days. Plants were considered as damaged if they were dead, flaccid, or fed upon by onion maggot but not flaccid. Because data were of a binomial nature, they were analyzed using PROC GENMOD (SAS Institute Inc., 2001). Data are represented as the percentage of plants damaged by onion maggot in each plant age x egg density combination.

Ovipositional preference for different aged plants

This experiment also was conducted at NYSAES. Onion seeds were planted three weeks apart to obtain two age classes of plants. A single onion seed (var. 'Millenium') treated with the fungicide Pro-Gro[®] (20 g (AI)/kg of seed) was planted in a 15.24 cm x 15.24 cm plastic pot filled with muck soil from a nearby commercial farm. Plants were allowed to germinate in a growth chamber (16L: 8D, 21°C, 60%rh) after which time they were transferred to the greenhouse (16L: 8D) and watered as needed. After plants reached the one leaf stage, they were transferred outdoors and maintained in an onion-maggot free area.

Onion seeds planted on 30 July and 22 August yielded two age classes of plants (= two treatment levels) such that plants were approximately seven and three weeks old, respectively, when the experiment began on 15 September. The sizes of these plants corresponded with the sizes of the plants in the early (two to four leaves) and middle (one to two leaves) plantings in the planting date study during the time that oviposition would have peaked for first-generation onion maggots. No attempt was made to compare oviposition levels between plants representing the late planting from our planting date study and the others because the late-planted onions would have just begun emerging by peak onion maggot oviposition.

Ovipositional preference of onion maggot for “early-size” versus “middle-size” plants was evaluated in a two-choice test. Potted plants of each size were placed into mesh cages 46 cm long x 46 cm wide x 46cm high and held in a growth chamber (16L: 8D, 21°C, 60%rh). One early- and middle-sized plant was randomly assigned to each cage and exposed to seven female and three male onion maggot flies. Flies were offered water and a diet of brewer’s yeast, powdered milk, sugar and soy peptone (Ticheler, 1971) ad libitum. Two runs were conducted, with six replicates in the first and four in the second, yielding a total of ten replicates. The same cages and flies were used for both runs. Dead flies were replaced with live ones and new plants were placed in cages for the second run.

Flies were allowed to oviposit for 48 hours, after which time plants were removed and the numbers of eggs per plant counted. Most eggs were laid within the top one centimeter of soil around the base of the plants (although some were laid on onion foliage). The majority of onion maggot eggs are typically laid within this soil depth (Havakkula et al., 1992). Soil was placed on a black surface and eggs were sorted through with a paintbrush. Onion maggot eggs are white and clearly visible against a black background. Preliminary experiments indicated that an equal number of eggs were retrieved using this method compared with floating eggs in muck soil using water. However, counting eggs by sorting through the soil with a paintbrush was much less time consuming than floating eggs. Data were analyzed using a paired t-test implemented with PROC MEANS (SAS Institute Inc., 2001).

Results

Effect of planting date on onion maggot damage levels

Overall, onion maggot pressure at our field site was very high in 2003 (Figure 3.1). Female onion maggot fly activity was very low before 27 May, but showed an initial increase by 3 June indicating the start of the first generation (Figure 3.1).

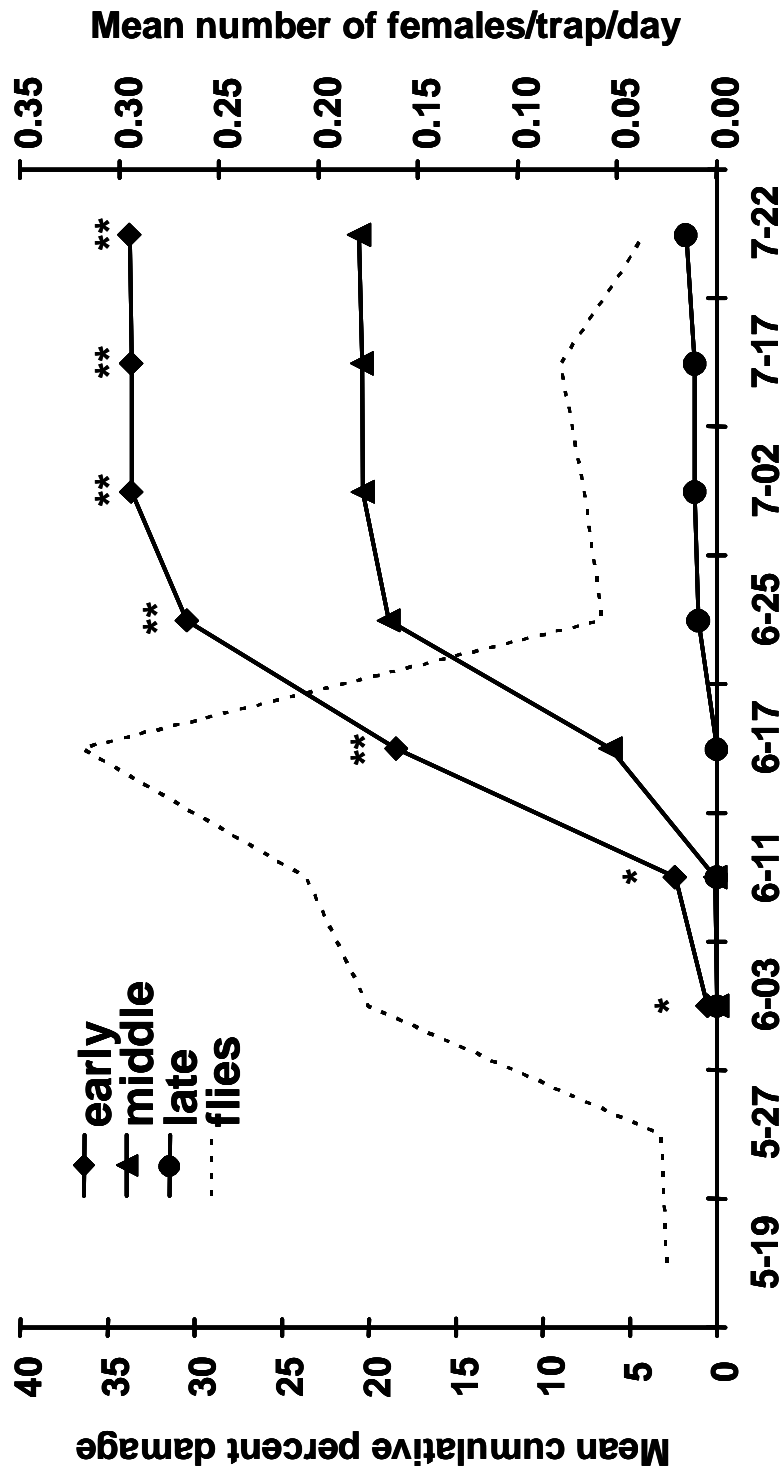


Figure 3.1 Mean cumulative percentage of early, middle, and late-planted onions damaged by onion maggot, *Delia antiqua*, and mean number of female onion maggot flies caught per sticky card per day for each sampling date. Dates for which there was a significant (experimentwise error = 0.05) difference in damage between early planted-onions and later planting dates are indicated by “*”, while dates for which damage was significantly different between all three planting dates are indicated by “**”.

Increases or decreases in female activity tended to precede corresponding changes in weekly rates of onion maggot damage (Figure 3.1). For example, damage in the earliest planting was first detected one week after the initial increase in first-generation female activity (Figure 3.1). Female activity declined dramatically between 17 and 25 June, marking the end of the first generation and the beginning of the second (Figure 3.1). The majority of damage occurred during the first generation, particularly between 11 and 25 June (Figure 3.1). Female onion maggot fly activity had accordingly peaked during this time period (Figure 3.1). Approximately 90% of all onion maggot damage in early and middle plantings occurred before 25 June and 59% of damage in late plantings occurred by this time. Larvae produced by this first generation of females were thus responsible for the majority of onion maggot damage to onion in our study.

The percentage of the initial stand of onion plants damaged by onion maggot differed significantly between planting dates ($F = 48.33$; $df = 2, 10$; $P < 0.0001$) and sampling dates ($F = 200.86$; $df = 7, 70$; $P < 0.0001$), with a significant interaction occurring between planting date and sampling date ($F = 29.89$; $df = 14, 70$; $P < 0.0001$). This interaction occurred because damage started occurring at different times and accrued at different rates in the three planting date treatments during the first generation of onion maggot flies (Figure 3.1). Damage appeared earliest (3 June) and accumulated fastest during the first generation in early plantings, appeared later (17 June) and accumulated at a lower rate in middle than early plantings during this time, and appeared last (25 June) at a very low rate in late plantings (Figure 3.1). These differences in the onset and rate of damage resulted in damage levels being significantly different between all three planting dates by the end of the first generation; mean damage levels were greatest in early plantings, intermediate in middle plantings and lowest in late plantings (Figure 3.1).

Overall damage levels and differences in damage between planting dates changed little throughout the rest of the study, because very little damage occurred during the second generation of onion maggot flies (Figure 3.1). Thus, mean damage levels were greatest at the study's end in early plantings (37%), intermediate in middle plantings (21%) and lowest in late plantings (2%) (Figure 3.1).

Effect of plant age and egg density on onion maggot damage levels

The percentage of plants damaged by onion maggot was similar between two and four week old plants, lower for six week old plants and lowest for eight week old plants across all egg densities (Figure 3.2). Thus plant age was nearly significant in explaining variation in plant damage among treatments ($\chi^2 = 3.02$; $df = 1$; $P = 0.0823$). Damage also significantly increased with increasing egg density ($\chi^2 = 12.17$; $df = 1$; $P = 0.0005$) (Figure 3.2). Differences in damage between plants of different ages varied with egg density (Figure 3.2), resulting in a significant egg density x plant age interaction ($\chi^2 = 5.51$; $df = 1$; $P = 0.0189$). For this reason, the remainder of the discussion will focus on this interaction.

The magnitude of differences in maggot damage between plants of different ages was most pronounced at densities of two eggs per plant and least pronounced at densities of 10 eggs per plant (Figure 3.2). At a density of 2 eggs per plant, 75 and 85% of two and four week old plants were damaged while only 35 and 25% of six and eight week old plants were damaged. Damage increased in all treatments when egg densities were raised to five eggs per plant (Figure 3.2). At this egg density six week old plants no longer displayed the marked resistance they had with two eggs per plant and sustained damage (80%) approaching that of the younger treatments (100%) (Figure 3.2). Damage in eight week old plants was still very low (30%) with five eggs per plant (Figure 3.2). At very high densities of 10 eggs per plant damage to plants of all ages was very high (Figure 3.2).

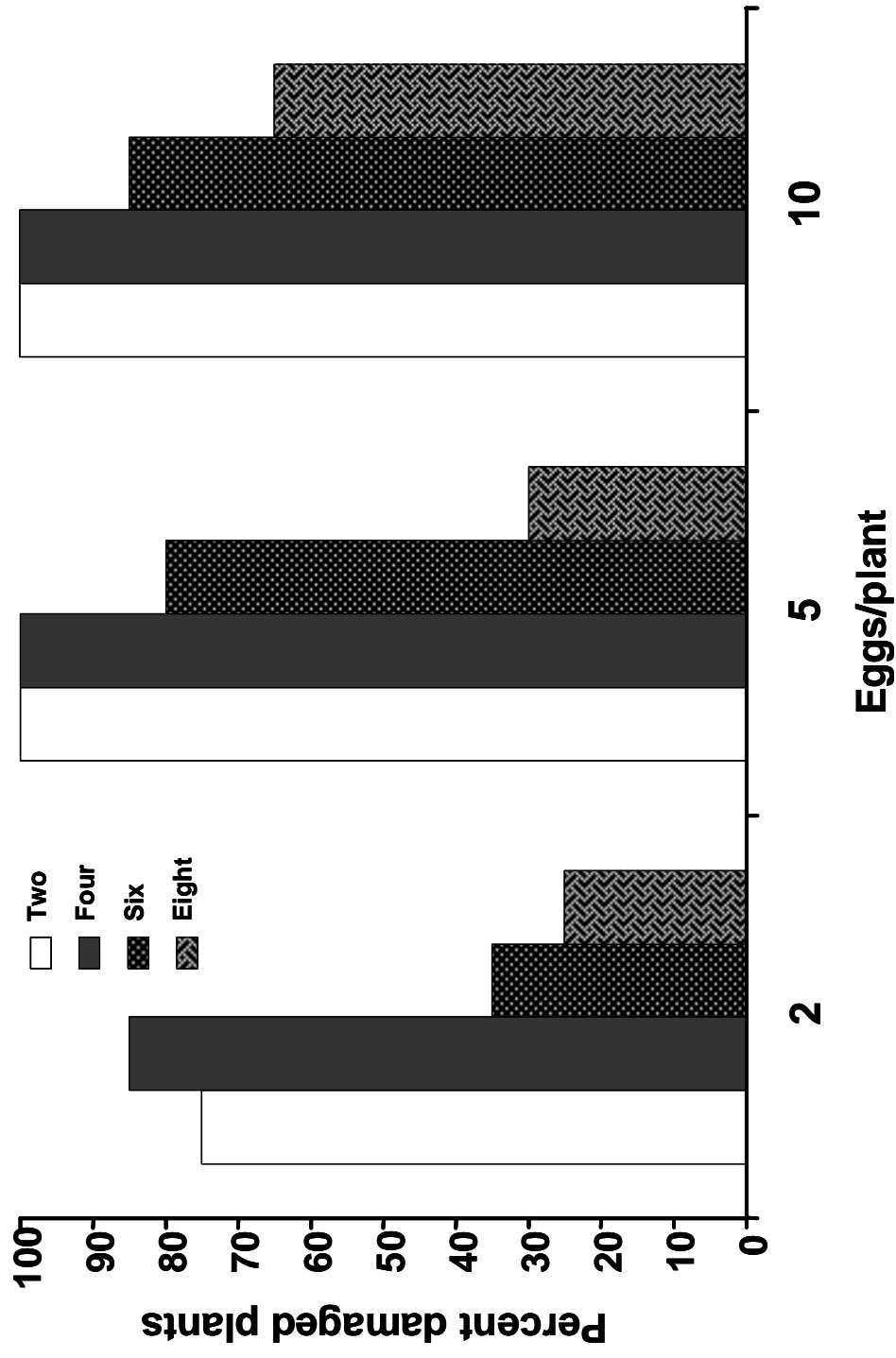


Figure 3.2 Percentage of plants damaged by onion maggot, *Delia antiqua*, for two, four, six and eight week old plants inoculated with two, five and ten onion maggot eggs per plant.

These results indicate that onion becomes more resistant to attack by onion maggot larvae as they mature, but that this defense breaks down under very high maggot pressure.

Ovipositional preference for different aged plants

Female onion maggot flies laid significantly more eggs on onions the size of early-planted onions than ones the size of middle-planted onions ($t = 2.39$; $df = 9$; $P = 0.0094$). Nearly four times more eggs were laid per early-sized onion compared with middle-sized onions (Figure 3.3).

Discussion

Delaying onion planting resulted in reductions in onion maggot damage in middle and late plantings relative to early plantings (Figure 3.1). On average, onion maggot damage was reduced by 43% and 95% in middle and late plantings, respectively, relative to early plantings. While delaying planting until 28 May (late planting) resulted in an acceptable level of onion maggot control (2% damage), delaying planting until 6 May (middle planting date) did not (21% damage). Levels of onion maggot damage above 10% are not acceptable to growers (Walters & Eckenrode, 1996).

Currently, a delay in planting constitutes an economic risk to growers. New York onion growers usually plant fields as early as temperatures permit to maximize the amount of time available for plants to bulb before lower temperatures and reduced photoperiod cause growth to revert to foliage in late summer (Brewster, 1994). Early abortion of bulbing can result in yield being suboptimal due to a reduction in bulb size (Brewster, 1994).

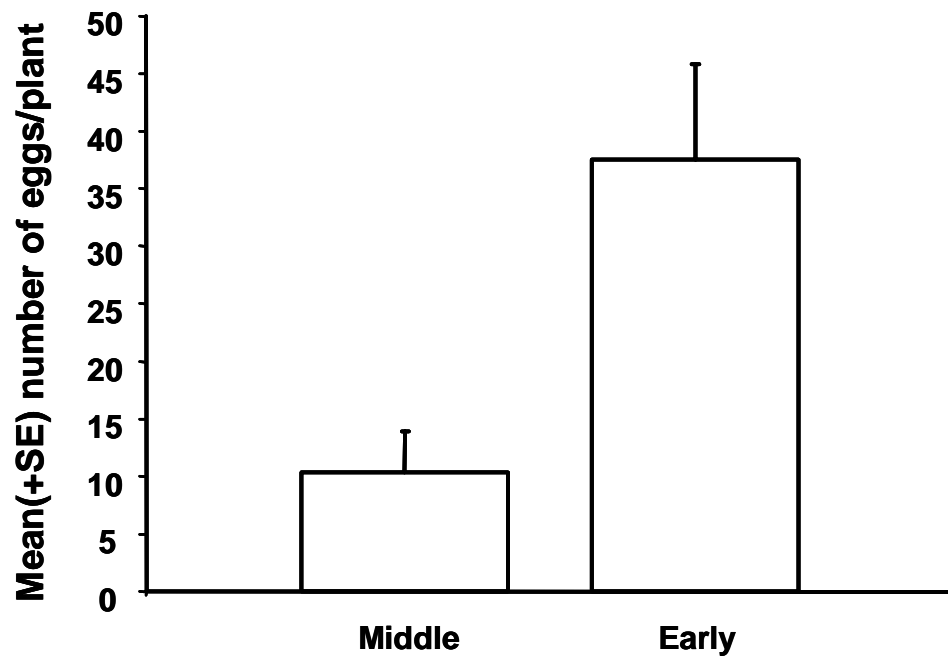


Figure 3.3 Mean (+SE) number of onion maggot, *Delia antiqua*, eggs laid on plants the size of middle and early-planted onions at peak first-generation oviposition.

Although delaying planting by three weeks (middle-planted treatment) would reduce the risk of aborted bulbing relative to a six week delay (late-planted treatment), the reductions in damage gained by this three-week delay were not sufficient on their own to control the high infestations of onion maggot at an acceptable level. Thus, a three-week delay in planting is not currently a viable way to manage high infestations of onion maggot in New York without the use of other controls. This strategy could be effective in fields where onion maggot pressure is known to be less severe. A six-week delay would not be an acceptable approach because this dramatic delay would have a negative impact on yield. If shorter season varieties with acceptable agronomic qualities could be developed, this option could become feasible.

The differently timed plantings from our planting date study should have had different inherent levels of resistance to onion maggot due to their different ages. Early plantings were seven to eight weeks old during 3 and 11 June when first-generation female onion maggot flies were most active, middle plantings were four to five weeks old at this time and late plantings had just begun emerging. Our laboratory study indicated that six and eight week old plants are more resistant to onion maggot than two and four week old plants (Figure 3.2), suggesting that early plantings should have been more resistant to onion maggot attack by the first peak of fly oviposition. However, this resistance breaks down under high egg densities; older plants are little better at fending off maggot attack than younger plants under these conditions (Figure 3.2).

The fact that onion maggot damage was greater in these early plantings than less-resistant middle plantings suggests that egg densities may have been appreciably greater on these older plants. This increased egg density on early versus middle plantings likely resulted from older plants being more acceptable to ovipositing flies than younger plants, because females laid approximately four times more eggs on

early-sized than middle-sized plants in the laboratory (Figure 3.3). This preference is likely explained by the larger size of older plants. In particular, female onion maggot oviposition on onions increases with increasing stem diameter (Harris et al., 1987).

However, there are two important caveats that need to be addressed in regards to this interpretation of our data. Firstly, extending the results of laboratory studies to field situations should be done with caution. Resistance to onion maggot attack may not be expressed in the field the same way it is in the laboratory. Secondly, egg densities would not have to be greater in early relative to delayed plantings for early plantings to sustain greater damage if overall more early-planted onions received at least one or two eggs. For example, if 100 of our early- and 10 of our middle-planted onions received two eggs, 25 early- and nine middle-planted onions would have been damaged given resistance levels shown by plants of these ages (eight and four weeks old, respectively) in our lab trials. Thus, the greater resistance of early- relative to middle-planted onions may have resulted from greater numbers of early onions being attacked, rather than greater numbers of eggs being laid per early plant.

Late plantings most likely received low densities of eggs because they had barely emerged at the time of peak onion maggot oviposition. These plants thus escaped the damaging first generation of maggots by emerging after the first peak of oviposition. Plants that had emerged by this time were very small and were probably unattractive to ovipositing flies. Because most damage occurred during this time period, late plantings had sustained very low levels of damage by the end of the study.

The effectiveness of this latest planting in reducing onion maggot damage shows how altering crop phenology in relation to pest phenology can be an effective method of cultural control. Although it may not be practical for New York onions at this time, other crops may benefit from such a strategy. In Georgia, planting early-maturing soybeans four to six weeks earlier than usual allows plants to grow and

produce beans before the onset of harsh drought conditions (McPherson et al., 2001). Early-planted crops are also harvested before pests such as velvetbean caterpillar, *Anticarsia gemmatalis* (Hubner), and soybean looper, *Pseudoplusia includens* (Walker), become maximally abundant. As a result, defoliation of the crop by these pests is reduced (McPherson et al., 2001). Thus, altering planting date can be an effective means of improving control of insect pests in situations where it is practical, and can provide an alternative or supplement to insecticide use on these occasions.

References

- Brewster JL (1994) Onions and Other Vegetable Alliums. CAB International, Wallingford, UK.
- Brooks AR (1949) The identification of the commoner root maggots of garden crops in Canada. Mimeographed pamphlet. Department of Agriculture, Division of Entomology, Canada.
- Doane CC & Chapman RK (1952) Dusts and late planting control onion maggots. Bulletin, no. 498. University of Wisconsin, Madison, Agricultural Experiment Station, WI, USA.
- Eckenrode CJ (1985) Onion maggot damage increasing: Pesticide resistance calls for integrated pest controls. *American Vegetable Grower* June: 10-12.
- Eckenrode CJ & Nyrop JP (1995) Onion maggot management in New York, Michigan and Wisconsin. *New York's Food & Life Sciences Bulletin*, no. 144. Cornell University, NY, USA.
- Eckenrode CJ, Vea EV & Stone KW (1975) Population trends of onion maggots correlated with air thermal unit accumulations. *Environmental Entomology* 4: 785-789.
- Ellis PR & Eckenrode CJ (1979) The onion maggot and its control in New York. *New York's Food and Life Sciences Bulletin*, no. 79. Cornell University, NY, USA.
- Finch S, Cadoux ME, Eckenrode CJ & Spittler TD (1986) Appraisal of current strategies for controlling onion maggot (Diptera: Anthomyiidae) in New York state. *Journal of Economic Entomology* 79: 736-740.
- Harris MO, Miller JR & de Ponti OMB (1987) Mechanisms of resistance to onion fly egg-laying. *Entomologia Experimentalis et Applicata* 43: 279-286.
- Harris MO, Tolman JA & Svec HJ (1982) Onion maggot (Diptera: Anthomyiidae) resistance to some insecticides following selection with parathion or carbofuran. *The Canadian Entomologist* 114: 681-685.
- Havukkala IJ, Harris MO & Miller JR (1992) Onion fly egg distribution in soil: a new sampling method and the effect of two granular insecticides. *Entomologia Experimentalis et Applicata* 63: 283-289.
- Hoffmann MP, Petzoldt CH & Frodsham AC (1996) Integrated Pest Management for Onions. Cornell Cooperative Extension, NY, USA.

- Liu HJ, McEwen FL & Ritcey G (1982) Forecasting events in the life cycle of the onion maggot, *Hylemya antiqua* (Diptera: Anthomyiidae): Application to control schemes. *Environmental Entomology* 11: 751-755.
- Loosjes, M (1976) Ecology and Genetic Control of the Onion Fly, *Delia antiqua* (Meig.). Center for Agricultural Publishing and Documentation, Wageningen, The Netherlands.
- McPherson RM, Wells ML & Bundy CS (2001) Impact of the early soybean production system on pest populations in Georgia. *Environmental Entomology* 30: 76-81.
- Pearson CS & Cline MG (1958) Soil Survey: Ontario and Yates Counties, New York. Series 1949, No. 5. U.S. Government Printing Office, Washington, D.C., USA.
- SAS Institute Inc. (2001) Ver. 8.2. SAS Institute Inc., Cary, NC, USA.
- Taylor AG, Eckenrode CJ & Straub RW (2001) Seed coating technologies and treatments for onion: Challenges and progress. *HortScience* 36: 199-205.
- Ticheler J (1971) Rearing of the onion fly, *Hylemya antiqua* (Meigen), with a view to release of sterilized insects. In: *Sterility Principle for Insect Control or Eradication: Proceedings of a Symposium Jointly Organized by the IAEA and FAO and Held in Athens, 14-18 Sept. 1970*. International Atomic Energy Agency, Vienna, Austria, pp. 341-346.
- Walters TW & Eckenrode CJ (1996) Integrated management of the onion maggot (Diptera: Anthomyiidae). *Journal of Economic Entomology* 89: 1582-1586.