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thesis entitled

INSECT GROWTH REGULATOR, CYROMAZINE, CONTROL OF ONION MAGGOT (*DELIA ANTIQUA* (MEIGEN)) AND EFFECTS ON POSSIBLE BIOLOGICAL CONTROLS

presented by

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has been accepted towards fulfillment
of the requirements for

Masters degree in Entomology

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Date May 14, 1999

INSECT GROWTH REGULATOR, CYROMAZINE, CONTROL OF ONION MAGGOT (*DELIA ANTIQUA* (MEIGEN)) AND EFFECTS ON POSSIBLE BIOLOGICAL CONTROLS

By

Sheila M. Ebert

A THESIS

Submitted to
Michigan State University
In partial fulfillment of the requirements
For the degree of

MASTERS OF SCIENCE

Department of Entomology

1999

ABSTRACT

INSECT GROWTH REGULATOR, CYROMAZINE, CONTROL OF ONION MAGGOT (*DELIA ANTIQUA* (MEIGEN)) AND EFFECTS ON POSSIBLE BIOLOGICAL CONTROLS

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Total carabid counts were generally higher in the cyromazine treated area versus the chlorpyrifos treated area of a field. However, each of the carabid species counted did not have higher numbers in the cyromazine areas. Total staphylinid counts were also more numerous in the cyromazine areas at all sites in the second year. Count comparisons of other coleopterans and other arthropods were made. The patterns of beetle activity peaks were examined.

Trenches were used to increase and decrease ambient carabid concentrations in an onion field. The relative survival of onion plants on which maggot eggs had been placed did not differ between the high and low carabid concentrations. At harvest, the number of eggs that survived did not depend on the carabid concentration treatments. However, eighty percent fewer maggots survived in the treatments with higher carabid concentrations.

Cyromazine and chlorpyrifos were tested on a variety of soils for control of onion maggot and for possible effects on onion germination and growth. These tests were done by growing onions with these insecticides and with a no insecticide control on different soils in two greenhouse studies and one field study. These results indicate that cyromazine does not differ from chlorpyrifos in its efficacy at the different soil organic matter contents tested. However, soil organic matter content does effect the growth of onions and the performance of the insecticides.

DEDICATION

To the memory of Florelda Kraemer and Rosella Ebert

ACKNOWLEDGEMENTS

Thank you to:

- Maria Davis and Ed Grafius who gave me this opportunity to learn "how to do science."
- My committee members Doug Landis and Darryl Warncke who listened to my ideas and guided me through onions and beetles,
- Walter Pett, Beth Bishop, and everyone in who worked in the Grafius lab during my time at Michigan State University,
- Karim Maredia and Melanie Kaeb who expanded my time as a masters student into a larger experience,
- Jim Miller and his egg rearing lab members, in particular, Adam Peters for insight into onion maggot behavior,
- The students, staff and professors who helped, taught, inspired, listened, and made my time at MSU a good experience,
- Ilka and Steve Gilmer, Piera Giroux, Nathan Seigert, and my mother,
- Ron Gnaggy who was patient with the number of weeds in my plots and with me.

I would like to extend a special thank you to the people who let me onto their land and graciously let me "muck" with their muck, the onion growers Mr. Dave Brink, Mr. Bruce Schreur, Mr. Bernard Emelander, Mr. Don Krummrey and their families.

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INTRODUCTION

Onions (Alliaceae: *Allium cepa*) are a major vegetable crop in the United States, second only to lettuce production by weight (Kortier-Davis et al. 1995). In 1996, Michigan growers planted 2511 ha of dry bulb onions with a production value of $15.5 million (MASS 1997). Most of these onions were directly seeded into histosols, commonly referred to as "muck" soils which have high organic matter content (Lucus 1982). Histosols typically have good water retention, high nitrogen content, and simple nutrient management and harvest practices (Zandstra et al. 1996).

The insect pest complex in onion production is relatively simple in Michigan. Onion thrips, *Thrips tobaci* (Lineman), scrape the leaves and feed on the sap causing damage to the leaves; large enough numbers can result in reduced onion yields and increased incidences of bacterial rot (Cornell University 1983). However, the most significant insect pest of onions in Michigan is the onion maggot, *Delia antiqua* Meigen (Diptera: Anthomyiidae). In severe years, onion maggot can reduce onion stand in commercially treated fields by 40-80% (Zandstra et al. 1990).

Foliar insecticide sprays have been used to kill adult flies; soil drenches and granular insecticides have been used to kill larvae. Historically, the common practice was to apply granular insecticides in the seed furrow at planting and then follow with foliar sprays as often as once a week starting in June (Liu et al. 1982). The result of this intensive exposure is that the onion maggot is now resistant to many insecticides (Howitt 1958, Guyer & Wells 1959, Harris & Svec 1976, Harris et al. 1981, and Carroll et al.

1991). Chlorpyrifos (Lorsban, Dow Elanco, Indianapolis, Indiana), an organophosphate insecticide, and cyromazine (Trigard, Novartis, Greensboro, North Carolina), an insect growth regulator, are the only remaining chemicals registered and effective for use against onion maggot.

Cyromazine is an insect growth regulator that stiffens the larval cuticle via an undetermined mode of action and prevents molting (Kotze & Reynolds 1991). In the early 1980's, cyromazine was found to be useful against species of flies. It has been used against leaf miners, *Liriomyza trifolii* (Burgess), cultivated mushroom pests, *Lycoriella auripila*, and has been fed to cattle and fowl to kill flies in feces (Shen & Plapp 1990). Hayden and Grafius (1990) reported the potential of cryromazine as a management tool for onion maggot. Cyromazine was first used against onion maggot as a soil drench; it is now being incorporated into an onion seed treatment which results in the low dosage of 50g of active ingredient per kg seed (Grafius et al.1984, Grafius & Boylan-Pett 1991, Davis & Grafius 1992).

This thesis investigated three questions:

1. What is the impact of cyromazine versus conventional insecticide controls on non-pest, surface dwelling insects? Cyromazine is an insect growth inhibitor that may have fewer negative impacts than conventional insecticides on natural enemies of the onion maggot (Miller et al. 1981, Samsoe-Petersen 1985, Wills et al. 1990) and, therefore, might lend itself to a more integrated approach to control onion maggot.
2. What impact do these surface insects, particularly members of the family Carabidae, have on the survival of the immature stages of *D. antiqua*? Does carabid predation affect the level of maggot damage to the onion plants?

3. How effective are cyromazine and chlorpyrifos on soils of different organic matter content? Despite the success of cyromazine for onion maggot control, there have been some reports of failures. During the growing season of 1995, Grafius and Davis (1996) found cryromazine ineffective at one field site. They suggested that this might have been due to dry conditions, failure of pellet breakdown, or soil with low organic matter content.

LITERATURE REVIEW

Onion maggot. The onion maggot, *Delia antiqua* Meigen (Diptera: Anthomyiidae), is a serious onion pest. In Michigan, onion maggots have three generations per year; the third generation over-winters in the soil as pupae and emerges as adult flies in May. Fifty percent emergence occurs at approximately 400 $DD_{4.4°C}$ (Carruthers 1979, Whitfield 1981). Newly emerged flies require a day for the exoskeleton to dry and harden (Carruthers 1982). In the period before oviposition, the flies forage and are commonly found in field borders visiting dandelions, *Taraxacum officinale* Weber (Baker 1927) or other wild flowers (Carruthers 1982).

After a preovipositional period of about 10 days, the flies mate (Carruthers 1979). The females lay their eggs at the base of onion seedlings. Perron and LaFrance (1961) found in field cage experiments in Quebec that the mean numbers of eggs laid per female of each generation were 57.8, 36.2, and 24.3 respectively. Havukkula et al. (1992) reported that on average a *D. antiqua* female lays 15% of her eggs on the surface to 2 mm below, 24 % 2-4 mm deep, 22% 4-6 mm deep, 13% 6-8 mm deep, 7% 8-10 mm deep, 18% 10-15 mm deep, and a few deeper.

Onion maggot eggs require 50 $DD_{3.88}$ to hatch (Carruthers 1979). Larvae feed on the onion bulbs for 2 to 3 weeks, passing through three instars. One maggot destroys an average of 28 small seedlings (onions in the loop stage with diameter at the soil surface of 1 mm) before completing development (Workman 1958). The larvae then pupate, and adults emerge in July. By this time, the onions have developed a papery skin over the bulbs that is more resistant to onion maggot attack. Therefore, summer generation female flies prefer to lay their eggs on previously damaged onions (Finch & Eckenrode

1985, Hausmann & Miller 1989). Second generation flies emerge in August and September and lay eggs on onions left behind in the field after the harvests in August-October. The first generation larvae, therefore, have the greatest direct effect on the yield and quality of the onion crop. In severe years, onion maggot can reduce onion stand in commercially treated fields by 40-80% (Zandstra et al. 1996).

Management of onion maggot. Historically, onion maggot has been managed primarily with chemical controls. The common practice was to apply granular insecticides in the seed furrow at planting and then follow with foliar sprays as often as once a week starting in June (Liu et al. 1982). The result of this intensive exposure is that the onion maggot is now resistant to cyclodiene, organophosphate, carbamate, and pyrethroid insecticides (Howitt 1958, Guyer & Wells 1959, Harris & Svec 1976, Harris et al. 1981, and Carroll et al. 1991). Foliar sprays used against adults are ineffective and may have contributed to resistance development (Finch et al. 1986). Application of granular insecticides in the seed furrow by itself is effective against the very damaging first generation of onion maggot (Ritcey et al. 1991). Chlorpyrifos (Lorsban, Dow Elanco, Indianapolis, Indiana), an organophosphate insecticide, and cyromazine (Trigard, Novartis, Greensboro, North Carolina), an insect growth inhibitor, are the only remaining chemicals effective registered for use against onion maggot.

Resistance to chlorpyrifos is increasing in Michigan (Grafius and Pett 1991), and soil insecticides such as chlorpyrifos are known to be toxic to many species of carabids (Mowat & Coaker 1967, Critchley 1972, Tomlin 1975, Clements et al. 1988, Asteraki 1991, Bale et al. 1992), potential predators of the onion maggot. Clements (1988) concluded that chlorpyrifos sprays reduce total adult and larval carabid populations with some variations between species and that some of the insecticide effects persist at least 18 months. In a non-replicated study by Warner (1986), soil applied chlorpyrifos may have reduced the numbers of the carabid *Bembidion quadrimaculatum* L.. Floate et al. (1989) found that while chlorpyrifos was toxic to *Bembidion obscurellum* Motschulsky and *B. quadrimaculatum* in the lab, in the field *Bembidion* spp. mortality was lower in sprayed plots between 3-16 days but not significantly lower between 17-47 days. Funderburk et al. (1990) found in peanut fields that spiders but not carabid numbers were significantly reduced by chlorpyrifos. In Michigan, most onions are grown on organic soils. Organophosphate pesticides maintain a higher concentration in organic soils than in mineral soils (Szeto & Price 1991).

In the early 1980's, cyromazine, an insect growth inhibitor, was found to be useful against species of flies. It has been used against leaf miners, *Liriomyza trifolii* (Burges), cultivated mushroom pests, *Lycoriella auripila*, and has been fed to cattle and fowl to kill maggots in feces (Shen & Plapp 1990). Hayden & Grafius (1990) reported the potential of cryromazine as a management tool for onion maggot. Cyromazine was first used against onion maggot as a soil drench; it is now being incorporated into an onion seed treatment which results in the low dosage of 50g active ingredient (AI) / kg seed (Grafius et al.1984, Grafius & Boylan-Pett 1991, Davis & Grafius 1992).

Cyromazine stiffens the larval cuticle via an undetermined mode of action and prevents molting (Kotze & Reynolds 1991). The physiological effects of cyromazine have been studied in the Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann) (Diptera: Tepritidae), by Vinduela & Budia (1994). They found in cyromazine treated flies a conspicuous swelling of the integument in the anterior region of the body, with a local thinness of the cuticle due to the gap between the epicuticle and the procuticle. In the exoskelton there was discontinuity between the procuticle layers, abnormal thickening of the cuticle and disorganization and elongation of the epidermic layer; only the epicuticle was unaffected. There were also some effects on the muscles such as altered mitochondria, distorted area of fiber arrangement, and less fiber packing. They concluded that cyromazine acts at the hormonal level, but its effects on the skeletal muscles also indicate a protein involvement in the mode of action.

Cyromazine is a pesticide that may have fewer negative impacts than conventional pesticides on natural enemies of the onion maggot (Miller et al. 1981, Samsoe-Petersen 1985, Friedel 1986, Wills et al. 1990) and therefore, might lend itself well to a more integrated approach to control onion maggot.

Predatory natural enemies of the onion maggot. The predators of *D. antiqua* adults and immatures that have been investigated include birds (Kastner 1930, Loosjes 1976), toads *Bufo bufo* L. (Loosjes 1976), the tachinid fly *Coenosia tigrina* (L.) (Perron et al. 1956), and *Scatophaga stercoraria* (L.) (Loosjes 1976). Carabidae and Staphylinidae are the most researched predators of the immature stages of *D. antiqua* and its relatives, the cabbage maggot *Delia radicum* (L.) (=*Hylemya brassicae* Bouche) and the turnip maggot *Delia floralis* (L.). Trehern (1916) observed in the laboratory that carabids attack cabbage maggot eggs. Wishart et al. (1956) showed predacious beetles destroy up to 70% of cabbage maggot eggs and concluded that carabids are more important predators than staphylinids. Hughes (1959) and Hughes & Salter (1959) found that carabids destroy more than 90% of *D. radicum* eggs. Coaker & Williams (1963) found that although carabids are important *D. radicum* egg predators, staphylinids were more effective.

Coaker (1965), using barriers drenched in pesticide to alter carabid densities, showed that the survival of *D. radicum* is inversely related to the numbers of the predatory carabids present. He stated that the carabids are responsible for up to one third of the total egg mortality, though it varies from site to site and with species composition. Later in the cabbage maggot life cycle, Coaker suggested that mortality is due to other sources, staphylinids being an important source. Wayman et al. (1976) found that the ground beetle, *Stenelophus comma* (Fabr.) in addition to being an efficient predator of immature *D. radicum* in the laboratory, when attracted to cabbage plots by black lights could reduce cabbage maggot damage.

However, Van Dinther (1972) investigating Bembidion species by radioactive monitoring estimated that the role of carabids as natural enemies of cabbage root flies is minimal. Uba Yaman (1990) stated that in the Netherlands 97% of cabbage root flies are destroyed prior to their adult stage when natural enemies are present; without natural enemies the mortality is 80%. Thus mortality due to predation is only 17%.

Work by Wishart et al. (1956), Coaker & Williams (1963) Coaker (1965), Perron (1972), Drummond (1982), Andersen & Sharman (1983), Tomlin et al. (1985) all thought that the genus Bembidion to be a promising *Delia* spp. egg predator. Haynes et al. (1980) developed a conceptualization of the onion agroecosystem showing levels of interaction within the object of control (*D. antiqua*) and the monitored environment. The only carabid named in the model was Bembidion sp. Grafius and Warner (1989) reported that *B. quadrimaculatum* could potentially remove 60% of *D. antiqua* eggs from the field.

B. quadrimaculatum predation is higher when eggs are placed on the soil surface than when eggs are placed 1 cm deep (70% versus 17.5%). However, large portions of *D. antiqua* eggs are laid beneath the soil surface. Waymann et al. (1976) compared over a 24 h period *S. comma* predation on *D. radicum* eggs that were either exposed or covered with sand. They found that when unstarved S. comma found 65% of the covered and 92% of the uncovered eggs. When starved, S. comma found 85% of the covered and 94% of the uncovered eggs.

Haynes et al. (1979), Drummond (1982), and Motyka and Edens (1984) have found many species of carabids inhabit onion fields in Michigan. Tomlin et al. (1985) and Drummond (1982) conducted feeding trials with some of these species that showed an ability to eat onion maggot eggs and larvae.

Pitfall trapping. Pitfall traps have been used extensively to monitor the number and activity of surface-active invertebrates, especially Coleoptera and Araneida (Halsall 1988). However, pitfall traps have some important shortcomings. Surrounding vegetation may impede carabid movement and affect trap catches (Greenslade 1964). Weather may influence the amount of carabid locomotor activity and therefore trap catches (Briggs 1961). Greenslade (1964) found that different species vary in susceptibility to pitfall traps; smaller beetles were less susceptible to traps. However, Halsall (1988) found capture rates between a sample of species were unrelated to beetle size, speed of movement or diurnal behavior. Pitfall trap size, shape, and composition also have been found to affect trap catch (Luff 1973, Spense et al. 1994). Chiverton (1984) demonstrated that the content of the gut affected capture of a carabid species.

These reports support Briggs's (1961) conclusion that pitfall traps are of little value for the direct estimation of absolute populations.

Baars (1979) demonstrated that the use of continuous pitfall sampling could be used as a relative measure of the size of carabid populations. In the present work, comparisons of populations were made within individual fields with the same vegetation and under the same management practices. Against these arguments, pitfall traps seemed adequate.

There is some question as to the reliability of pitfall traps for assessing the impact of pesticides on populations of ground-dwelling arthropods. Edwards and Thompson (1975) found that the neurologically active insecticides cause hyperactivity that enhances catches in sprayed plots relative to unsprayed ones and that pitfall catches are influenced by beetle immigration. Chiverton (1984) concluded that reducing prey populations by the application of insecticides results in hungrier carabid beetles with consequently higher activity. Since pitfall trap catches are determined not only by population size but also activity, he argues that, "pitfall-trap catches alone cannot give a true measure of the effects of insecticides on carabid populations in the field." In a peanut field, Dixon & McKinlay (1992) hypothesized that after being sprayed with insecticide the pest (aphids) falls off plants. The beetles then ate the aphids and were less hungry therefore less active and less likely to be trapped; later increases in catches may have been due to hungry and thus more active beetles. In the onion system, the availability of eggs or maggots, which are already on or in the ground, is probably not increased due to the insecticides. Floate et al. (1989) found much higher toxicity of chlorpyrifos to *Bembidion* species in the laboratory than in the field and suggested that adult immigration and residual toxicity influence pitfall catches and recovery of carabid populations after spraying. These arguments against the use of pitfall traps except Dixon and McKinley (1992), result from higher numbers of carabids caught in sprayed areas.

Profiles of carabids frequently caught during the course of these studies

***Poecilus chalcites* Say**

Size 10.5-13 cm

Feeding. In a feeding study by Best and Beegle (1977), *Poecilus chalcites* fed on larvae but did not feed on any vegetable material. Kirk (1975) reported that *P. chalcites* eats eggs of western corn rootworm (*Diabrotica virgifera* LeConte) and pursues and eats larvae and adults in the laboratory. There is little cannibalism among adults but larvae ate eggs of the same species and were a quite cannibalistic stage (Kirk 1975).

Habitat. *P. chalcites* occurs throughout Eastern North America (Lindroth 1969). It prefers low, poorly drained fields where the soil is moist but not waterlogged. These fields retain clods and cracks that provide living places. *P. chalcites* will remain in a field year after year regardless of crop being grown. Kirk (1975) speculated that this presence in some fields year after year and none in other fields indicates favorable breeding sites are limited. Very rainy and wet conditions are favorable for larvae.

Life cycle (20-23°C) (Kirk 1975)

Stage	**Days**
Egg	6.8
1st stadium	9
2nd stadium	10.4
3rd stadium	14.1
Prepual	2.4
pupal	7.8
Total	50.5

The following is a summary from Kirk (1975) except where noted.

In South Dakota, *P. chalcites* overwinters 5-15 cm below the soil surface as an adult and emerges as early as mid April if the soil thaws. There is increasing activity from May until about mid-July after which there is a decrease until mid August when an equal size second activity period starts and lasts through September. The second peak includes the new generation adults.

Oviposition occurs in late May to mid August by overwintered adults. Peak ovipostion is in mid-June with most ovaries spent by late July. Females place their eggs in earthen cells beneath the soil surface. After eclosion the larvae probably live in the existing spaces between soil agglomerates or make temporary burrows by pushing their way between loose soil. The larvae pupate 2-15 cm below the surface. Females of the new generation remained sexually immature until the following spring.

The number of teneral adults peaked in early August. Teneral adults are fully colored within one day of eclosion and are soft for one week. They become active on surface and some fly at night. Lindroth (1969) reported that repeated captures in drift material suggested good powers of flight. Kirk (1975) thought that they only occasionally fly in low numbers. He believed flight to be limited and with little dispersal from favorable breeding sites. *Poecilus chalcites* can travel a maximum distance of 91 m/day but most individuals disperse relatively little averaging m/d (Best et al 1981). *P. chalcites* does not burrow.

***Anisodactylus sanctaecrucis* (Fabr.)**

Size. 8.3-10.5 mm

Feeding. Adults are not very canabalisitic…

Habitat. *A. sanctaecrucis* is transamerican (Lindroth 1969). A, sanctaecrucis prefers moist soil such as crop land moist and poorly drained and is found in soil trash and clods with *Poecilus lucublandus*, *Poecilus chalcites*, *Stenolophus comma*, *Harpalus herbivagus* (Say), *Clivinia inpressiforons* (LeConte), *and Evarthrus alernans* (Casey) (Kirk 1977).

Life cycle (20-23°C) (Kirk 1977)

Stage	**Days**
Egg	5.7
1st stadium	7.52
2nd stadium	7.6
3rd stadium	8.7
prepupal	3.41
pupal	7.1

Mean developmental period takes 40 days

The following is a summary from Kirk (1975) except where noted.

Anisodactylus sanctaecrusis hibernate as adults and are active from spring thaws to late September. From early June through August, the adults are good fliers. Kirk (1977) noted that, "in the spring, those disturbed in the field readily took flight, and I saw them in May flying in the midst of heavy daytime flights of *Stenolophus comma*." These adults probably lay eggs during May, June and early October. Eggs are more fragile than most other carabid species. The teneral adults overwinter before ovipositing. Females are known to produce eggs for as many as 3 years. Adults prepare overwintering chambers beneath the soil surface by early October

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***Stenolophus comma* Fabr.**

Size. 5.5-7.7mm

Habitat. *S. comma* is widely distributed in North America. Lindroth (1969) reported that *S. comma* was found in open, usually sandy but not very moist places near water. However, Rivard (1964) found that the species preferred moist, open ground with sparse vegetation. Kirk (1975), in a more in-depth investigation, found *S. comma* in rangelands, pastures, and in fields of the commonly grown crops. He found the largest populations in cropland where the organic content of the soil was high and the soil moisture was above average for the general area. Kirk found that *S. comma* is common in soil cracks, the series of spaces in the soil beneath soil clods, in tunnels in the soil and under the surface trash in moist situations. When conditions are dry the beetles were found deeper in soil cracks

Feeding. *S. comma* has been suspected of causing damage to corn, however Kirk (1975) did not find strong evidence for this behavior. Pausch (1979) found *S. comma and S. lecontei* to be primarily carnivorous (prefer insect eggs or small larvae) but they will feed on nonanimal food when animal food is not available. Larvae, which are highly cannibalistic, apparently feed on microorganisms that enter or grow in the burrows. In the laboratory, adults eat only dead or weak adults unless overcrowded (Kirk 1975).
In a laboratory feeding study, *S. comma* would feed on the eggs and newly hatched larvae of house flies and on dead western corn rootworms (*Diabriotica virgifera*) adults, but not live rootworm larvae (Pausch 1979).

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Life cycle (20-23°C) (Kirk 1975)

Stage	**Days**
Egg	5.4
1st stadium	10.5
2nd stadium	9.3
3rd stadium	12.8
Pupa	9.4
Total	47.4

The following is a summary from Kirk (1975) except where noted.

Adult *S. comma* are present in the field during all months of the year in South Dakota. Maximum activity on the soil surface is during June and early July with minimal activity during August and September. Adults hibernate in burrows 2-20 cm beneath the soil surface. All females remained sexually immature until after overwintering. The first oviposition occurs 15 days after the beetles emerge from hibernation, unless inactivated by cold weather. Ovipostion peaks between mid May to July. Eggs are laid singly in cells located off burrows that the females create in moist soil. Teneral adults appear from Mid June to mid October. Newly emerged adults congregate, perhaps waiting until weather conditions are suitable for flight.

When temperatures are over 15°C and the wind not over 10 knots from late April to mid June, heavy dispersal flights occur during the day. The flights are especially heavy when the field has been disturbed. After mid June, dispersal flights occur at night. Flights are correlated with damp soil, higher RH, warm air, and not more moderate wind speed.

S. comma is attracted to light. Wayman et al. (1976) found in cabbage plots lit with black lights that *S. comma* numbers were higher and subsequent damage due to cabbage maggot (*Delia radicum*) was less.

***Pterostichus melanarius* Illiger**

Size. 12-19mm

Habitat. Barlow (1970) found *P. melanarius* in open or semi-open areas and in both cultivated and uncultivated land. He thought that it avoided barren places and preferred areas with deep, rich soil.

Lifecycle. *P. melanarius* hibernate mainly in the larval stage, although some adults overwinter. Adults have one activity-abundance cycle per year, which begins in May and ends in October with the greatest numbers in July and August. *P. melanarius* are summer-autumn breeders and females are gravid mainly in August and September. Gravid females were present throughout the activity cycle but the proportion of gravid to terneral females vary during the cycle. Some of the teneral females are not gravid until late July.

Clivinia impressifrons Lecont

Size. 5.9-7.0 mm

Habitat. Found in Eastern North America south to Texas. Lindroth 1968 reported them found in sandy lake shores (Lindroth 1969).

The following summary is from (Pausch and Pausche 1980) except where noted:

Feeding. Adults and larvae are primarily carnivorous but will feed on corn seed when their primary food is absent or in short supply. They eat house fly eggs and larvae as well as corn rootworm eggs and larvae, which they prefer over vegetation, seeds and artificial diets. The larvae are extremely cannibalistic.

C. impressifrons hibernates as an adult and is found active in soil in Illinois as early as the end of March. It is trapped through the summer until the temperature is below 20C, with very few found after July. When spring temperatures are above normal, *C. impressifrons* activity peak occurs during May or June. However, when spring temperatures are below normal, they peak in June or July. Lindroth (1968) reported that *C. impressiforns* is apparently an excellent flier, caught at light traps. Pausch and Pausche (1980) also found this species at light traps.

Poecilus lucublandus Say

Size. 9-14 mm

Habitat. *P. lucublandus* is found across North America and is commonly found in cultivated fields with high moisture (Kirk 1971) and is most abundant in fields that are damp but not waterlogged and is common in soil cracks. It is often in close association with *S. comma* (F.), *P. chalcites* (Say), *Harpalus herbivagus* Say, *Amara carinata* (Le Conte) (Kirk 1971).

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Feeding. *P. lucublandus* feeds on insects and prefers dead invertebrates over live ones (Best and Beegle 1977). Adults are cannibalistic when crowded in the laboratory (Kirk 1971).

Life cycle (20-23°C) (Kirk 1971)

Stage	***Days***
Egg	7
1st stadium	11
2nd stadium	13
3rd stadium	31
prepupal	4
pupal	10
Total	76

P. lucublandus are spring breeders and have one generation per year. Adults overwinter beneath the soil under crop residues in cultivated fields or pastures. There are two periods of activity during the season. Kirk (1971) measured the activity of *P. lucublandus* and found it slightly active at 5° C and quite active at 10-15°C. Teneral adults are found in traps during August to September and early October. The first period of activity is in the spring, greater than fall activity. Adults do not fly.

Kirk (1971) surmised that they probably lay eggs in cells off of soil cracks or clods and have peak oviposition in June (May-Sept). The late summer period of adult activity is from late August through September. They have continual egg production and renewed production if conditions are favorable. The larvae are more subterranean in their habits than adults.

ACTIVITY DENSITY OF CARABIDAE AND STAPHYLINIDAE IN ONION FIELDS TREATED WITH CYROMAZINE AND CHLORPYRIFOS FOR CONTROL OF ONION MAGGOT *DELIA ANTIQUA* (MEIGEN) (DIPTERA: ANTHOMYIIDAE)

ABSTRACT

Pitfall trap sampling of commercial onion fields in southern Michigan in chlorpyrifos and cyromazine treated areas was done over the 1996 and 1997 growing seasons. Total carabid numbers were generally significantly higher in the cyromazine treated areas compared to numbers in the chlorpyrifos treated areas of fields. However, not all species had higher numbers in the cyromazine areas. Total staphylinid numbers were also more numerous in the cyromazine areas at all sites in the second year. Comparisons of numbers of other coleopterans and other arthropods were made and the seasonal patterns of activity were examined.

Introduction

To construct an integrated pest management strategy for onion production, it is important to understand the impacts of chlorpyrifos and cyromazine, the two currently available chemical controls of onion maggot, on ground dwelling natural enemies. There have been few studies on the impacts of cyromazine on non-pest species, though it is not toxic to the adult coleopterans tested (Miller et al. 1981, Friedel 1986, Wills et al. 1990, Samsoe-Petersen 1993). However, cyromazine is toxic to Colorado potato beetle (*Leptinotarsa decemlineata* Say) larvae (Sirota & Grafius 1994).

The objective of this study was to compare the carabid and staphylinid populations in commercial fields treated with the organophosphate chlorpyrifos, or with cyromazine, an insect growth regulator. It was our hypothesis that the newer and "softer" insect growth inhibitor would be less disruptive to the natural biological controls. Pitfall traps were used to compare the soil surface fauna, the group of arthropods most likely to come into contact with controls applied to the soil (See literature review). Baars (1979) demonstrated that the use of continuous pitfall sampling could be used as a relative measure of the size of carabid populations. In the present work, comparisons of populations were made within individual fields with the same vegetation and under the same management practices.

Materials and Methods

Sites. Four commercial onion fields in southern Michigan were used as field sites, one near Grant (Newaygo Co.), two (one in 1997) near Hudsonville (Ottawa Co.), and one near Stockbridge (Ingham Co.) (Figure 1). Farm and field descriptions are listed in Table 1. The crops of the previous season were different at each farm. All of these

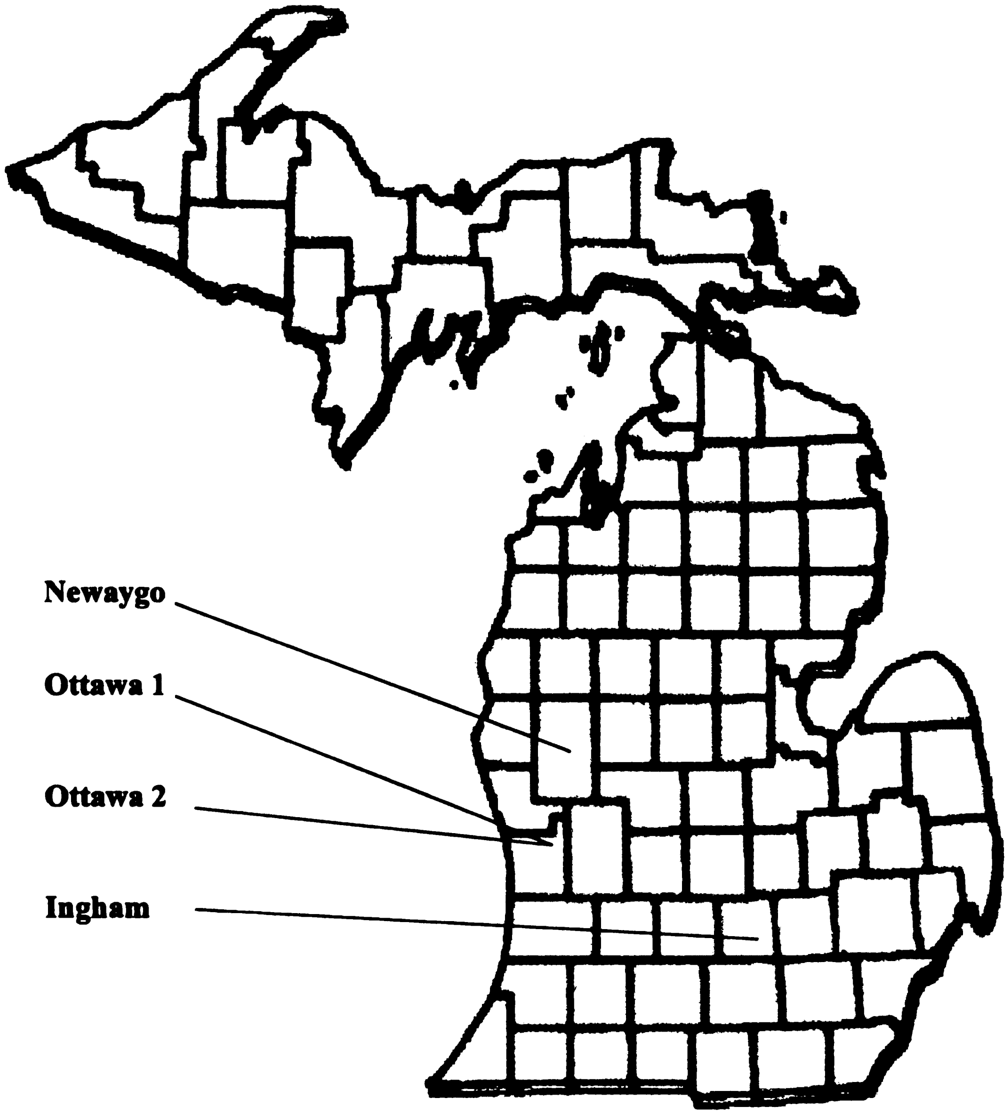


Figure 1. Map of field sites in Michigan

Table 1. Farm field sites and descriptions. Different fields were used in successive years at each farm.

Farm	Experiment year: previous rotation	Farm description
Ottawa 1	1996 : Celery 1997 : Celery	No raised beds. Four onion rows per bed. Limited cultivating during season. No foliar insecticide sprays for adult onion maggots. Used spray threshold for thrips. High organic muck.
Ottawa 2	1996 : Onions	No rotation. High pesticide usage including foliar insecticides and extra soil drenches for onion maggot larvae. Cultivated frequently.
Newaygo	1996 : Carrots 1997 : Carrots	Raised beds. Three onion rows per bed. No foliar insecticide sprays for adult onion maggot. Used spray threshold for thrips. Sandy muck soil.
Ingham	1996 : Potato 1997 : Onions	Raised beds. Three onion rows per bed. No foliar insecticide sprays for adult onion maggots. Used spray threshold for thrips. Marl patches in muck soil. Spirea planted as hedgrows.

crops are full season crops. Potatoes form a full canopy cover and, therefore, there is probably little pesticide penetration to the soil. Celery and carrot canopies are not as continuous, though may inhibit pesticide penetration to the soil especially late in the season.

At each farm, the grower had a field in which he had planted a portion of the area with cyromazine coated seed (50g active ingredient (AI) per kg seed) and a portion with untreated seed and granular chlorpyrifos (5.7g AI per 1000 row m) placed in the seed furrow (Ottawa Co. 1996, site 1 fonofos was used instead of chlorpyrifos). It was in these adjacent chlorpyrifos and cyromazine field areas that comparisons of fauna were made.

Sampling methods. Activity densities, the number of beetles that enter the trap per unit time, were measured using pitfall traps that were protected from rain and irrigation by covers of aluminum flashing suspended 2-3 cm over the traps by nails. The pitfall traps were made out of two plastic containers. The outer container remained in the soil for the duration of the experiment and limited soil disruption when traps were checked. In 1996, the traps were made from Solo brand cups (9.5 cm dia., 10.5 cm deep) that contained 5 cm of 50% ethylene glycol. In 1997, the plastic cups (11 cm dia., 14 cm deep) contained 5 cm soapy water.

Traps were placed in diagonal lines in the fields. In 1996, there were five traps placed in two diagonal lines 12-18 raised beds apart. The space between traps within a line was 30 m. In 1997, there were nine traps in three diagonal lines 46 m apart. The space between traps within a line was 8-9 m. The trapped fauna was sorted to family; most carabids were identified to species level (Lindroth 1968).

Statistics. The numbers of a species, family, or group per insecticide treatment per field location was totaled for the entire trapping season. Means of seasonal catch per trap in the two treatments were compared via a 2-sample Poisson comparison test that was run as a log linear model with a Chi square table to obtain a critical value (PROC GENMOD, SAS Institute 1994). Since each field represented a single non-replicable experimental unit, numbers were not compared between fields. In the figures that follow, the arithmetic means are used.

Results and Discussion

Carabids. In 1996, *P. chalcites* (Say) was the most numerous carabid species at the two Ottawa Co. sites and the Ingham Co. site in the cyromazine, chlorpyrifos, fonofos areas (Table 2). In 1997, *A. sanctaecrucis* was the most numerous species in the chlorpyrifos areas, while *P. chalcites* was most numerous in the cyromazine areas at the Ottawa 1 and Ingham Co. sites. In both years, the most numerous species at the Newaygo site was *P. melanarius* in both insecticide treatments. It is interesting to note that in pitfall surveys of Michigan onion fields in the late 1970s and early 1980s report a different species composition. From early June to early September of 1981 and 1982, Motyka and Edens (1984) pitfall trapped carabids at two commercial fields in Newaygo Co. Only *A. sanctaecrucis* numbers averaged between 3-9 per collection date, while the rest of the carabid species including *P. chalcites* (=*Pterostichus chalcites*) and *P. melanarius* were rare (average <3 per collection date) or were absent. Drummond (1982) in 1978 and 1979 pitfall trapped carabids in commercial onion fields and found *Stenolophus* spp. (=*Agnoderus* spp.) and A. *sanctaecrucis* the most common. The numbers of *Amara* spp., *B. quadrimaculatum* (L.), *C. impressifrons*,

Table 2. Total number of common carabids and staphylinids caught in all traps per insecticide treatment over the entire trapping time, A=chlorpyrifos, B=cyromazine, C=fonofos.

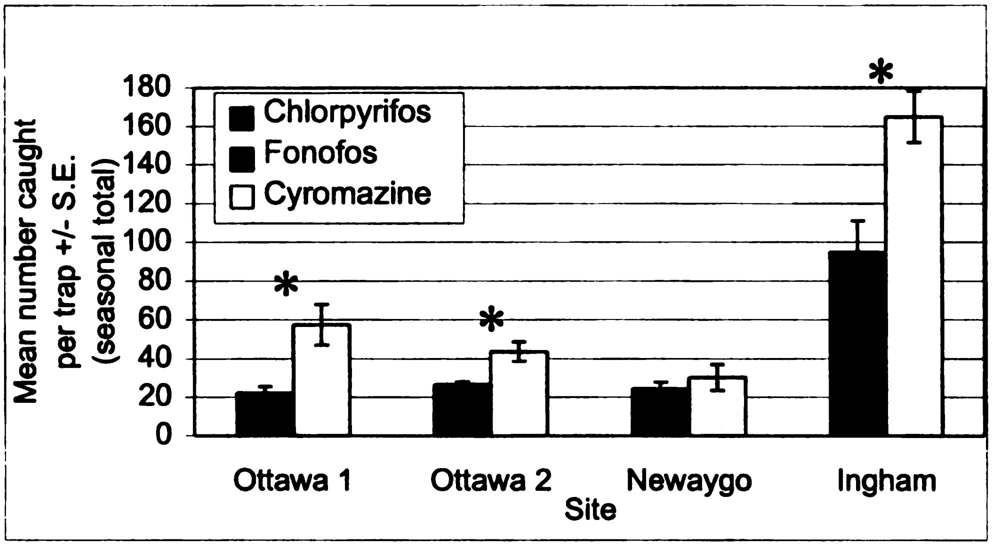
	Ottawa 1				Ottawa 2		Newaygo				Ingham			
	1996		1997		1996		1996		1997		1996		1997	
Carabid Species	**A**	**B**	**A**	**B**	**C**	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**
Poecilus chalcites	69	242	137	331	86	141	45	59	55	27	426	728	297	345
Poecilus lucublandus	9	4	7	2	2	2	15	18	6	8	2	4	24	25
Pterostichus melanarius	1	0	0	8	-	-	21	38	89	114	-	-	3	23
Anisodactylus sanctaecrusis	27	40	228	271	11	9	21	9	19	29	21	40	389	136
Stenolophus comma	3	0	21	19	1	1	4	9	19	26	1	3	42	18
Clivinia impressifrons	-	-	17	28	-	-	-	-	31	58	-	-	11	35
Agonum nutans	-	-	1	0	-	-	15	12	14	28	-	-	9	23
Loricera spp.	-	-	0	0	0	2	0	1	0	0	4	7	2	14
Bembidion quadramaculatum	1	0	0	2	1	0	1	2	3	17	3	24	17	5
Amara spp.	-	-	1	2	-	-	-	-	1	5	-	-	1	4
Colliuris pennsylvanica	-	-	0	1	-	-	-	-	0	1	-	-	0	3
Scarities subterraneus	-	-	-	-	2	0	-	-	0	0	-	-	-	-
Calasoma calidum	-	-	-	-	-	-	0	2	7	1	-	-	-	-
Harpalus	-	-	-	-	-	-	-	-	5	4	-	-	20	6
other carabids			10	17	1	0	0	1	14	19	0	4	9	10
Total carabids	**110**	**286**	**422**	**681**	**104**	**155**	**122**	**151**	**263**	**337**	**457**	**810**	**824**	**647**
Cicindela	-	-	-	-	-	-	-	-	-	-	-	-	1	7
Total Staphylinids	**13**	**16**	**71**	**108**	**3**	**12**	**22**	**22**	**282**	**483**	**19**	**80**	**104**	**185**

and *Pterostichus* spp. were up to an order of magnitude lower than the number of *Stenolophus* spp. and *A. sanctaecrucis*. Since the time of these studies, onion production systems have changed. There is now interplanting with barley or rye, more crop rotation, and less foliar insecticide use (Grafius 1999).

The mean total number of carabids was higher in the cyromazine area than in the chlorpyrifos fonofos area at all four farm sites in 1996 (Figure 2). This difference was significant in three of the four fields (Table 3). In 1997, at the Ottawa and Newaygo field sites there were significantly more carabids in the cyromazine areas than in the chlorpyrifos areas, however, at the Ingham site there were significantly more carabids in the chlorpyrifos area than in the cyromazine area. This difference between the 1997 Ingham county site and the other sites was due to *A. sanctaecrucis* and will be discussed later. The largest peak of carabid activity during the trapping period was in late June (Figure 3).

The number of *P. chalcites*, a common carabid at all field sites, was higher in the cyromazine treated areas than in the chlorpyrifos or fonofos treated areas at three of the four sites in 1996 (Figure 4). In 1997, there were fewer *P. chalcites* found even though the number of trapping days was higher in 1997. *P. chalcites* was significantly more numerous in the cyromazine treated area than in the chlorpyrifos treated area at Ottawa 1 and significantly less numerous in the cyromazine treated area than in the chlorpyrifos treated area at the Newaygo site. Reed et al. (1992) found that chlorpyrifos was more toxic to *P. chalcites* than fonofos and terbufos. The reported effects of terbufos and caroburan on *P. chalcites*

A. 1996



B. 1997

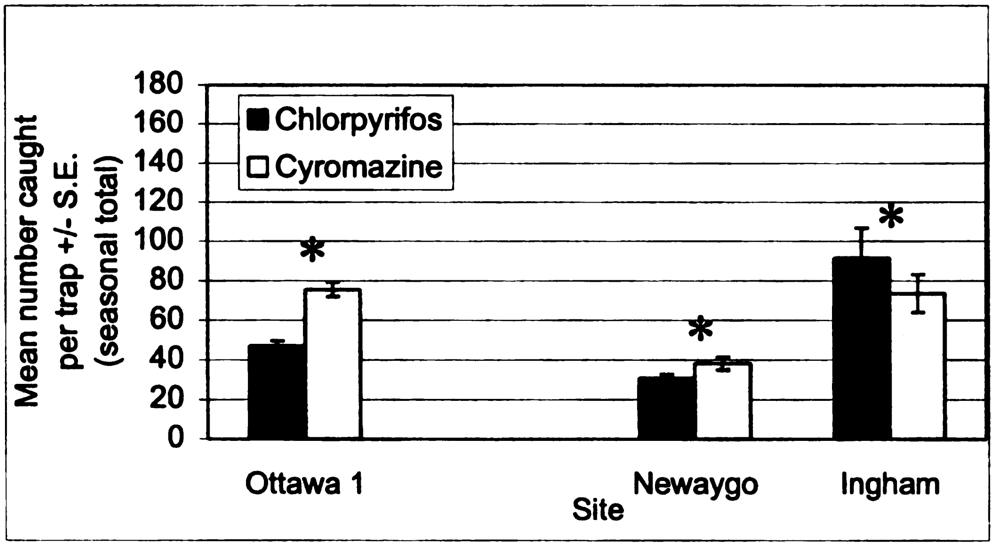


Figure 2. Total numbers of all carabids caught per trap in chlorpyrifos and cyromazine treated areas located in four different onion field sites during the 1996 and 1997 growing seasons

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(Poisson means = variance; * =significantly different, $p<0.05$)

Table 3. Chi square values for comparisons of total seasonal pitfall catches in chlorpyrifos and cyromazine in four different onion field sites in 1996 (5 traps per insecticide treatment) and 1997 (9 traps per insecticide treatment).

		Ottawa 1		Ottawa 2	Newaygo		Ingham	
		1996	1997	1996	1996	1997	1996	1997
All carabids	X^2	**0.1**	**9.7**	**21.2**	**3.2**	**7.0**	**95.4**	**17.4**
	P	***< 0.05***	***< 0.05***	***< 0.05***	***0.07***	*< 0.05*	***< 0.05***	***< 0.05***
Poecilus	X^2	101.9	82.8	13.4	1.8	9.7	79.9	3.5
chalcites	P	*< 0.05*	*< 0.05*	*< 0.05*	*0.17*	*< 0.05*	*< 0.05*	*0.06*
Anisodactylus	X^2	0.2	3.7	0.2	4.9	2.0	6.0	127.1
sanctaecrucis	P	*0.65*	*0.05*	*0.6545*	*0.0263*	*0.15*	*< 0.05*	*< 0.05*
Pterostichus	X^2	1.3	11.0		4.9	3.0		17.4
melanarius	P	*0.24*	*< 0.05*	-	*< 0.05*	*0.08*	-	*< 0.051*
Clivinia	X^2		2.7			8.3		13.1
impressifrons	P	-	*0.10*	-	-	*< 0.05*	-	*< 0.05*
Stenolophus	X^2	4.1	0.1	1.3	1.9	1.0	1.0	9.8
comma & lecontei	P	*< 0.05*	*0.75*	*0.24*	*0.16*	*0.30*	*0.31*	*< 0.05*
Poecilus	X^2	1.9	1.1		0.2	0.2	0.6	0.5
lucublandus	P	*0.16*	*0.26*	-	*0.60*	*0.59*	*0.41*	*0.45*
Bembidon	X^2	1.3	2.7	1.3	0.6	11.8	18.5	6.9
quadrimaculatum	P	*0.24*	*0.10*	*0.24*	*0.41*	*< 0.05*	*< 0.05*	*< 0.05*
Staphylinids	X^2	0.3	7.7	5.7	0	53.4	40.4	23.0
	P	*0.58*	*< 0.05*	*< 0.05*	1	*< 0.05*	*< 0.05*	*< 0.05*
Coleomegilla	X^2	4.8	0.8	0.3	0.2	0.2	5.8	1.5
maculata	P	*< 0.05*	*0.36*	*0.56*	*0.59*	*0.62*	*< 0.05*	*0.21*
Cocinella	X^2		3.3		6.9	14.5		1.3
septumpuntata	P	-	*0.07*	-	*< 0.05*	*< 0.05*	-	*0.25*
Hippodamia	X^2	4.1	5.2			0.0		5.0
spp.	P	*< 0.05*	*< 0.05*	-	-	*0.94*	-	*< 0.05*
Anthicids	X^2	72.3	9.1	13.5	0.4	5.3	18.4	68.1
	P	*< 0.05*	*< 0.05*	*< 0.05*	*0.50*	*< 0.05*	*< 0.05*	*< 0.05*
Spiders	X^2	23.3	9.2	6.9	0.3	2.5	4.0	7.0
	P	*< 0.05*	*< 0.05*	*< 0.05*	*0.53*	*0.11*	*< 0.05*	*< 0.05*
Earthworm	X^2					24.161		
	P					*< 0.05*		

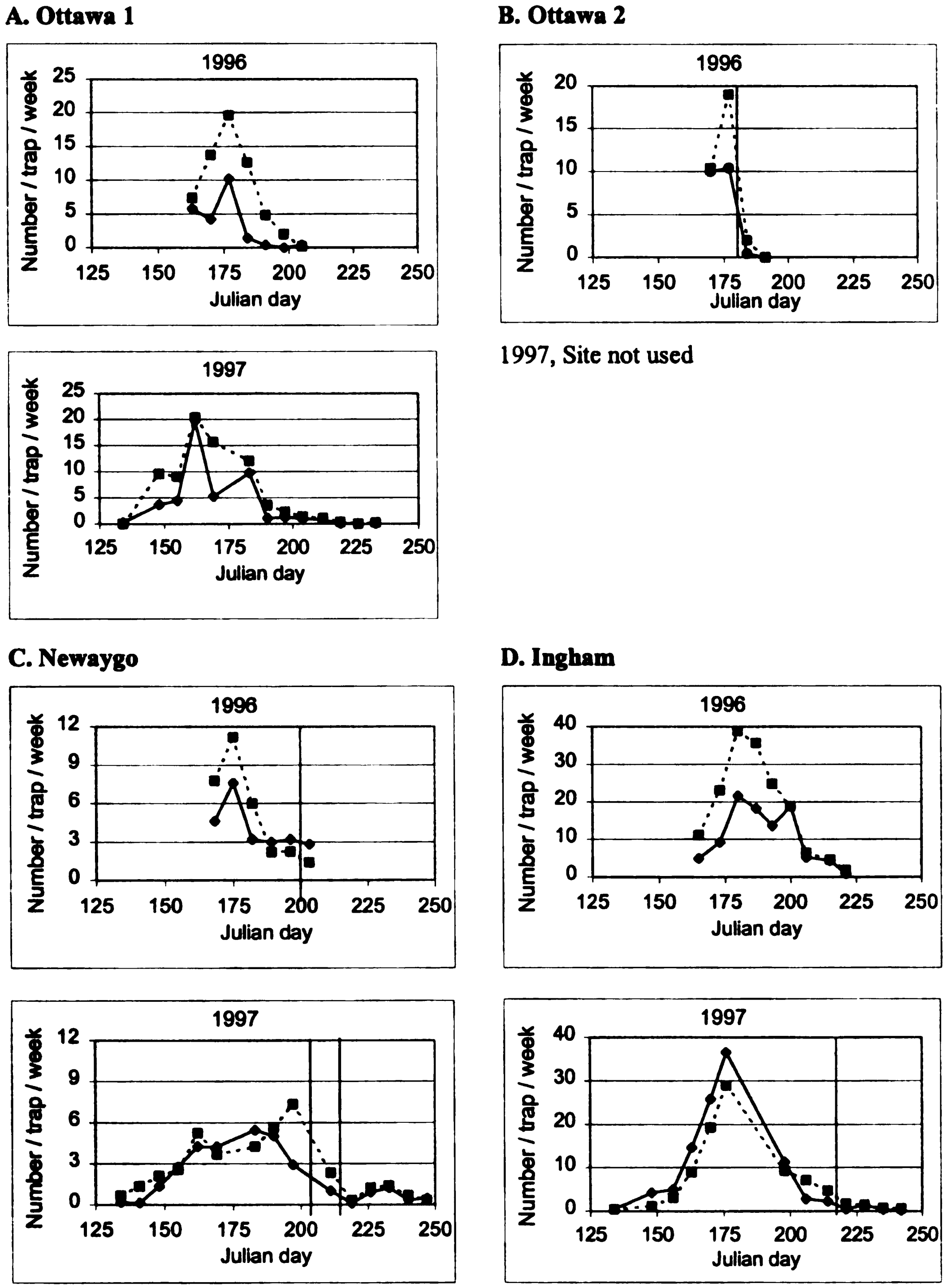


Figure 3. Number of **all carabids** caught per trap per week in chlorpyrifos and cyromazine treatments in four different onion field sites in 1996 and 1997.

(= chlorpyrifos, = fonofos, . = cyromazine, | = insecticide spray)

A. 1996

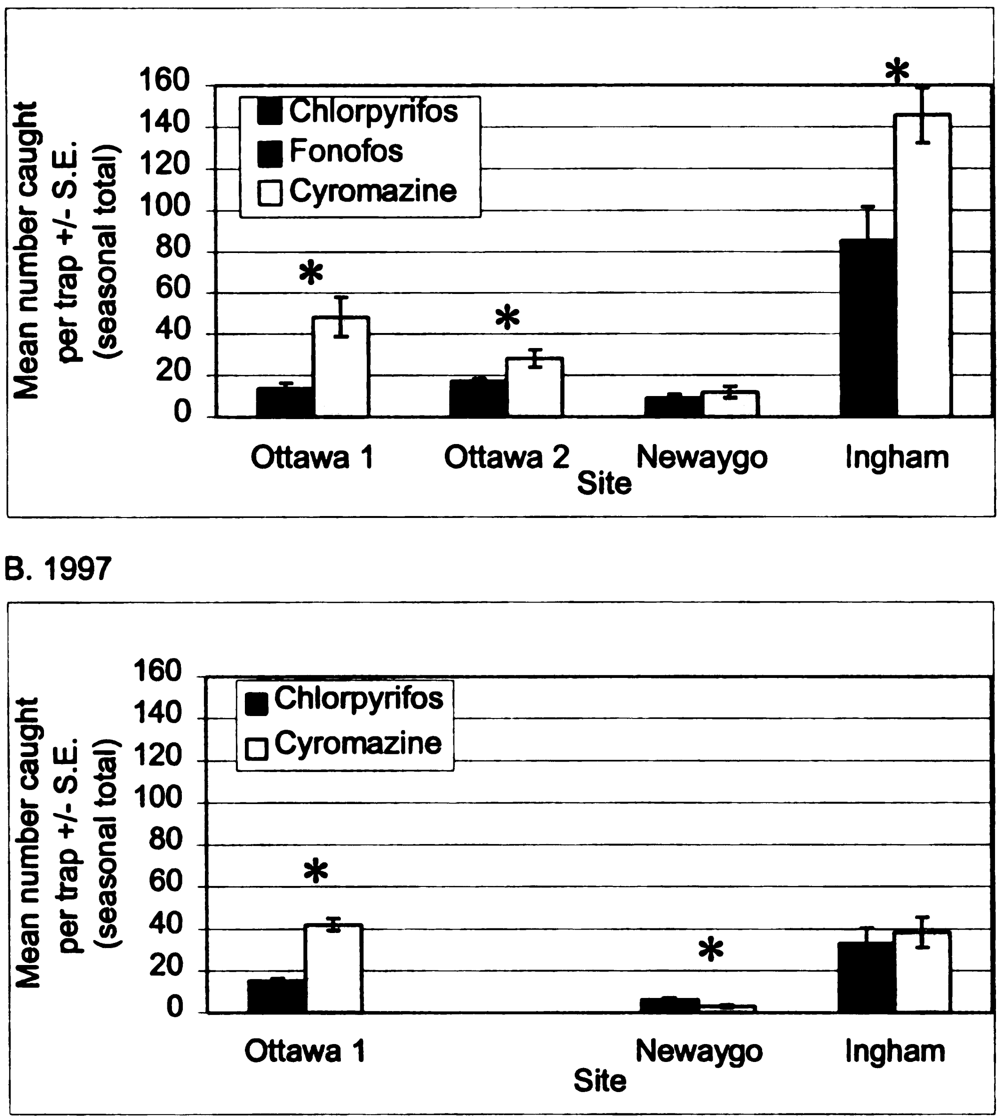


Figure 4. Total numbers of *Poecilus chalcites* caught per trap in chlorpyrifos and cyromazine treated areas located in four different onion field sites during the 1996 and 1997 growing seasons.

(Poisson means = variance; * =significantly different $p<0.05$)

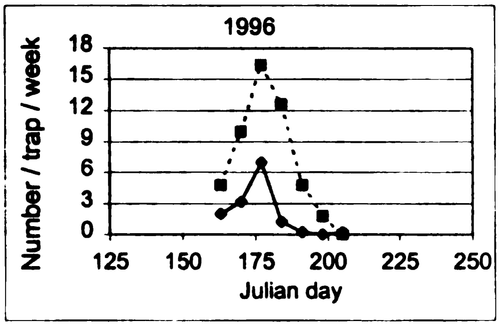
have ranged from toxic to no effect (Gholson et al. 1978, Hsin et al. 1979, Lesiewicz et al 1984).

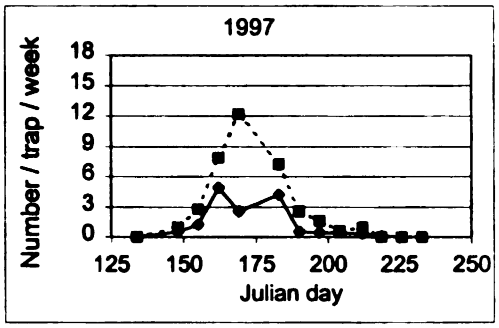
Kirk (1975) reported two equal size activity peaks of *P. chalcites* in South Dakota, one starting in May and peaking to July and a second in mid August through September. The second peak, normally made up of teneral adults was absent or occurred after the traps were removed from the fields in this study (Figure 5).

Many more *A. sanctaecrucis* were trapped in 1997 than in 1996. In both years there were field sites with significant differences between the numbers in the two treatments, but there was no prevailing pattern of *A. sanctaecrucis* numbers being higher in the cyromazine or chlorpyrifos areas (Figure 6). *A. sanctaecrusis* adults are good fliers from early June through August (Kirk 1977) and therefore may not have made contact with the insecticide or could immigrate quickly into the field. Activity peak occurred between 150-175 Julian days (Figure 7). Drummond (1982) found three peaks of adult activity in Michigan, though the largest peak was between 190-230 Julian days.

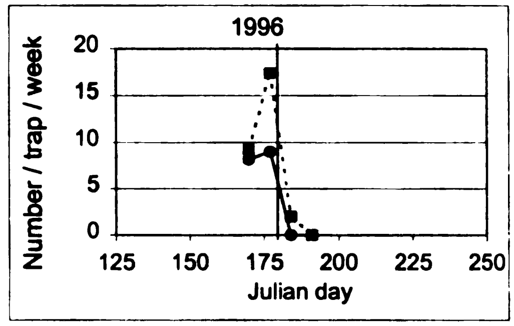
P. melanarius was the most common species found at the Newaygo site; significantly more were trapped in the cyromazine areas at the Newaygo site in 1996, the Ottawa 1 site in 1997, and the Ingham site in 1997 than in corresponding chlorpyrifos areas (Figure 8). While not statistically significant, the mean number of *P. melanarius* was higher in the cyromazine area than in the chlorpyrifos area at Newaygo in 1997. Bale et al. (1992) found *P. melanarius* to be susceptible to chlorpyrifos. The activity peak matched that reported by Barlow (1970) in July and August. (Figure 9).

A. Ottawa 1



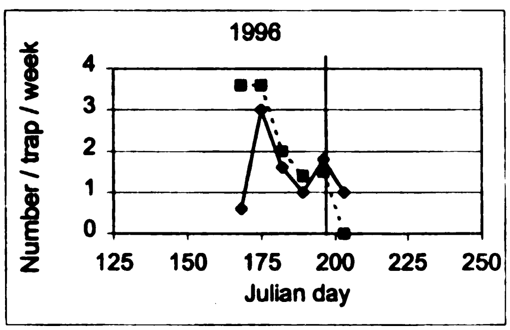


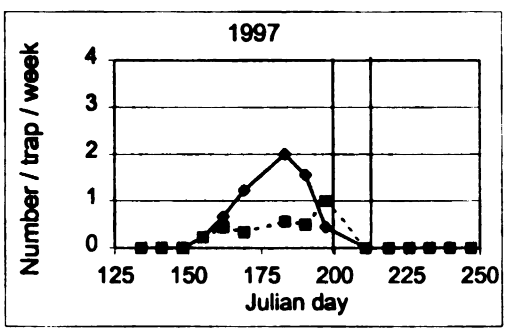
B. Ottawa 2



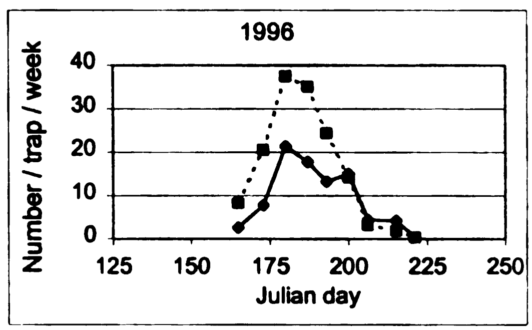
1997, Site not used

C. Newaygo





D. Ingham



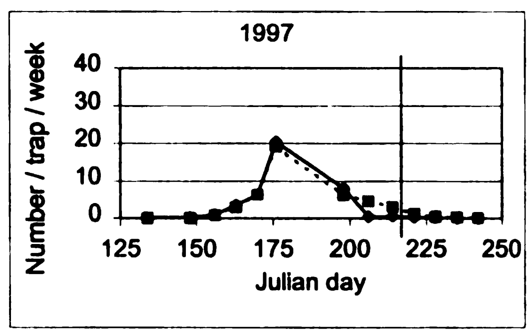
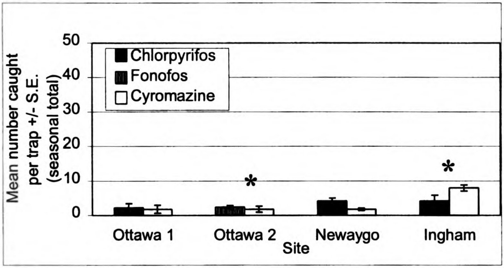


Figure 5. Number of *Poecilus chalcites* caught per trap per week in chlorpyrifos and cyromazine treatments in four different onion field sites in 1996 and 1997.

(= chlorpyrifos, = fonofos, = cyromazine, = insecticide spray)

A. 1996



B. 1997

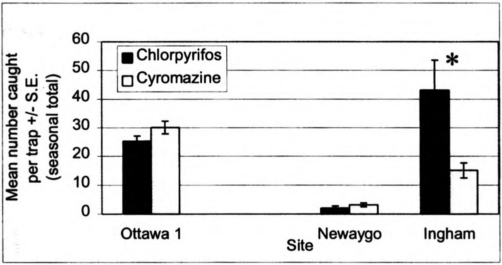
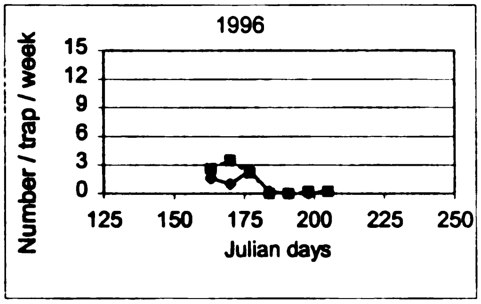
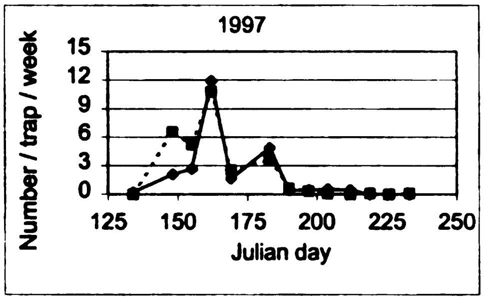


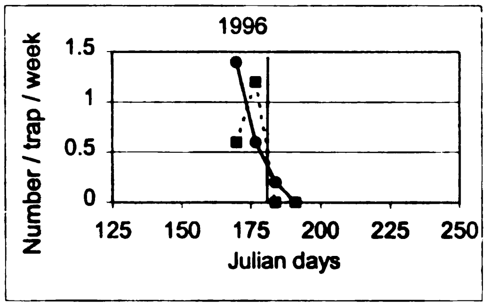
Figure 6. Total numbers of *Anisodactylus sanctaecrusis* caught per trap in chlorpyrifos and cyromazine treated areas located in four different onion field sites during the 1996 and 1997 growing seasons. (Poisson means = variance; * =significantly different, $p<0.05$)

A. Ottawa 1



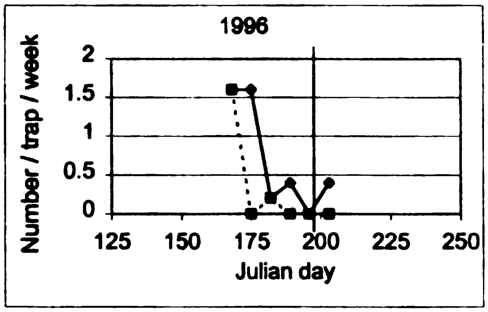


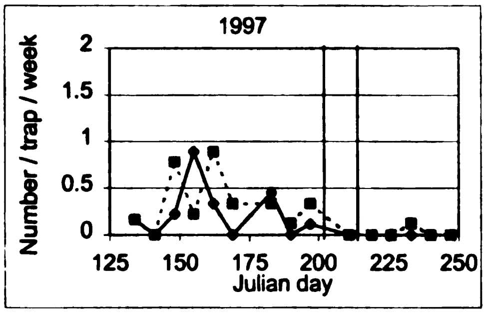
B. Ottawa 2



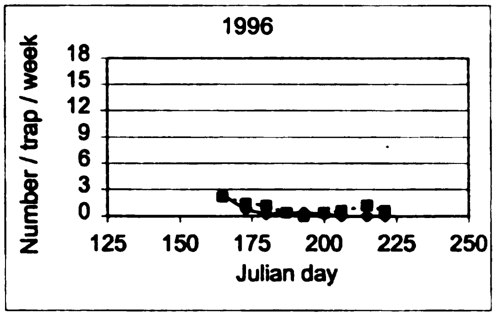
1997, Site not used

C. Newaygo





D. Ingham



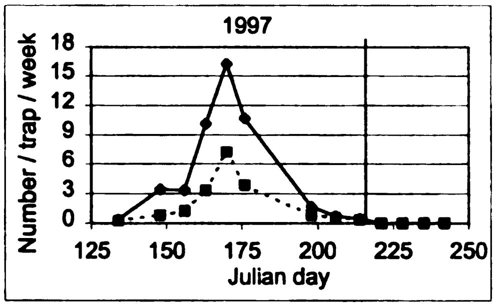
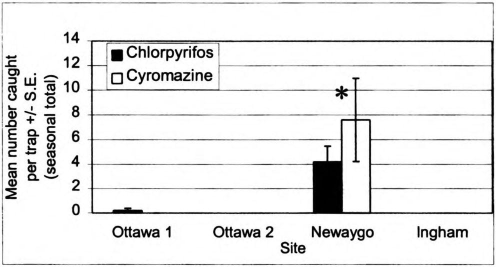


Figure 7. Number of *Anisodactylus sanctaecrusis* caught per trap per week in chlorpyrifos and cyromazine treatments in four different onion field sites in 1996 and 1997.

(= chlorpyrifos, = fonofos, . = cyromazine, = insecticide spray)

A. 1996



B. 1997

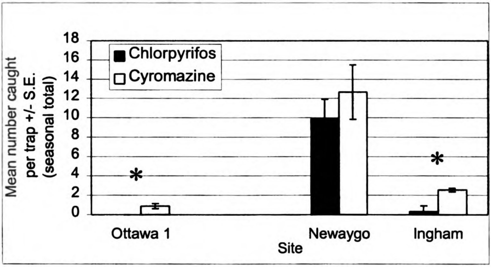


Figure 8. Total numbers of *Pterostichus melanarius* caught per trap in chlorpyrifos and cyromazine treated areas located in four different onion field sites during the 1996 and 1997 growing seasons. (Poisson means = variance; * =significantly different, p>0.05)

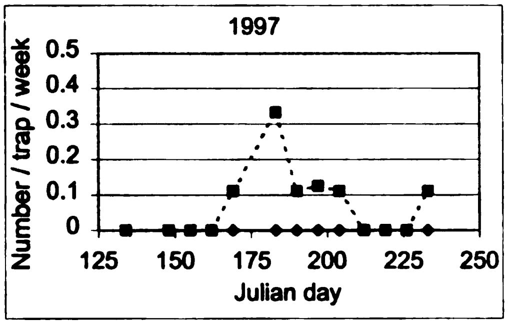
A. Ottawa 1

None caught

B. Ottawa 2

None caught

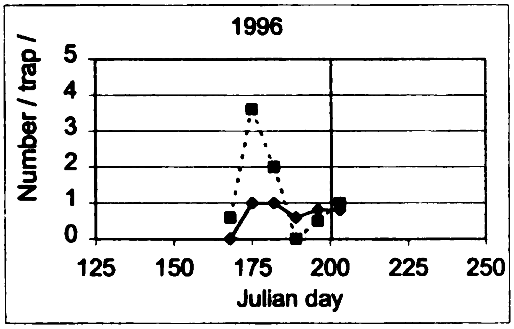
A. Ottawa 1



B. Ottawa 2

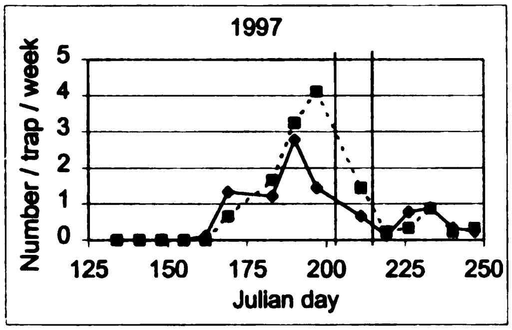
1997, Site not used

C. Newaygo



D. Ingham

None caught



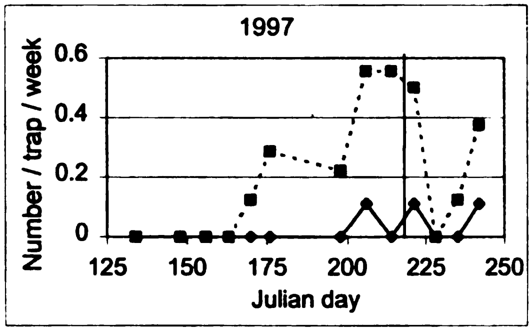


Figure 9. Number of *Pterostichus melanarius* caught per trap per week in chlorpyrifos and cyromazine treatments in four different onion field sites in 1996 and 1997.

(= chlorpyrifos, = cyromazine, = insecticide spray)

Another species that tended to be more prevalent in the cyromazine areas was *Clivina impressifrons* (Lecont). Two of the three fields had significantly more of *C. impressifrons* in 1997 (Figure 10). Drummond (1982) and Pausch & Pausch (1980) found that *C. impressifrons* had two generations per year, a summer peak (140-210 Julian day) and a fall peak (250-280 Julian day) which is similar to the 1997 catches in this study (Figure 11). *C. impressifrons* is a good flier, but it does have large fossorial legs and may come into contact with pesticides while digging in the soil.

Carabids such as *Stenolophus spp, Poecilus lucublandus* (Say), and *B. quadrimaculatum* had seasonal means that were not consistantly higher in either treatment (Figures 12-14). In South Dakota, *S. comma* has two peaks of adult activity, one in June and one in September (Kirk 1875), and in Wisconsin it has three peaks (Waymann et al. 1976). Drummond (1982) found in early spring a third peak in Michigan as well. The trapping period in this study only caught the second activity period (Figure 15). *Poecilus lucublandus,* in South Dakota, has a large spring activity peak and a smaller fall peak. In this study there does not appear to be a definite pattern (Figure 16).

While *Bembidion* spp. have been implicated as good *Delia* spp. egg predators in many studies, (Wishart et al. 1956, Coaker & Williams 1963, Coaker 1965, Perron 1972, Drummond 1982, Andersen et al. 1983, Andersen & Sharman 1983, Tomlin et al.1985, Grafius & Warner 1989) they are not the most frequently seen or caught carabid in the commercial onion fields. In a habitat study done by Warner (1986), more *B. quadrimacutlatum* were caught outside of an onion field than inside of it.

1 *Stenolophus comma* (F.)and *Stenolophus lecontei* Chaudoir have similar biologies and can only be taxonomically separated by the relative shape of the penis sac armature (Lindroth 1969). Therefore, they were not distinguished as two different species.

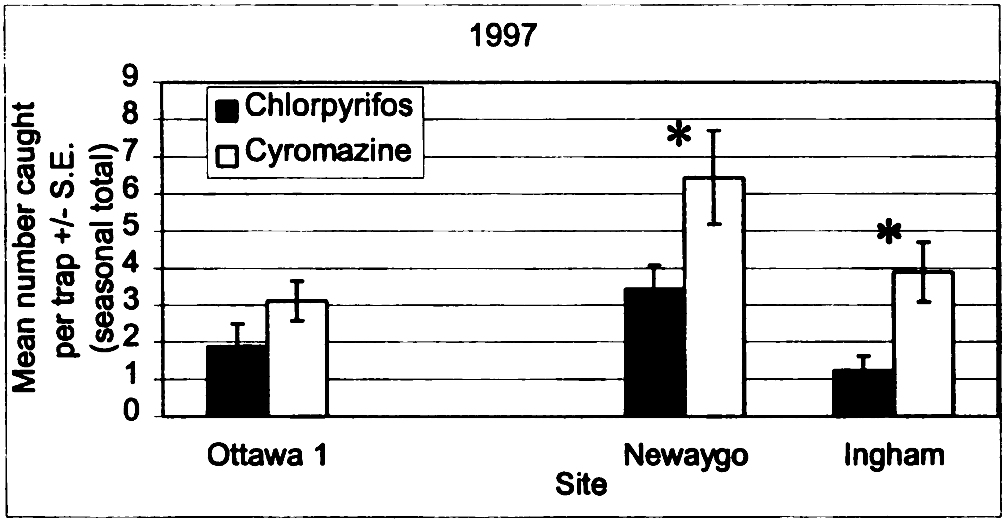
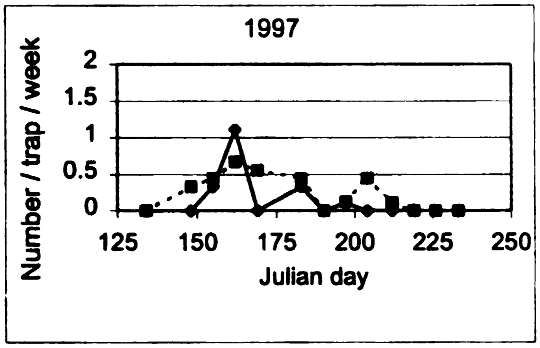


Figure 10. Total numbers of *Clivinia impressifrons* caught per trap in chlorpyrifos and cyromazine treated areas located in four different onion field sites during the 1997 growing season.

(Poisson means = variance; * =significantly different, p<0.05)

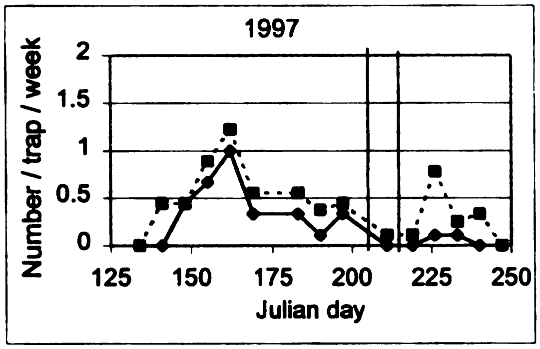
A. Ottawa 1



B. Ottawa 2

Site not used

C. Newaygo



D. Ingham

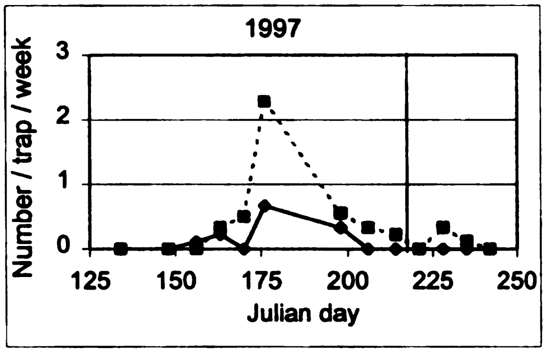
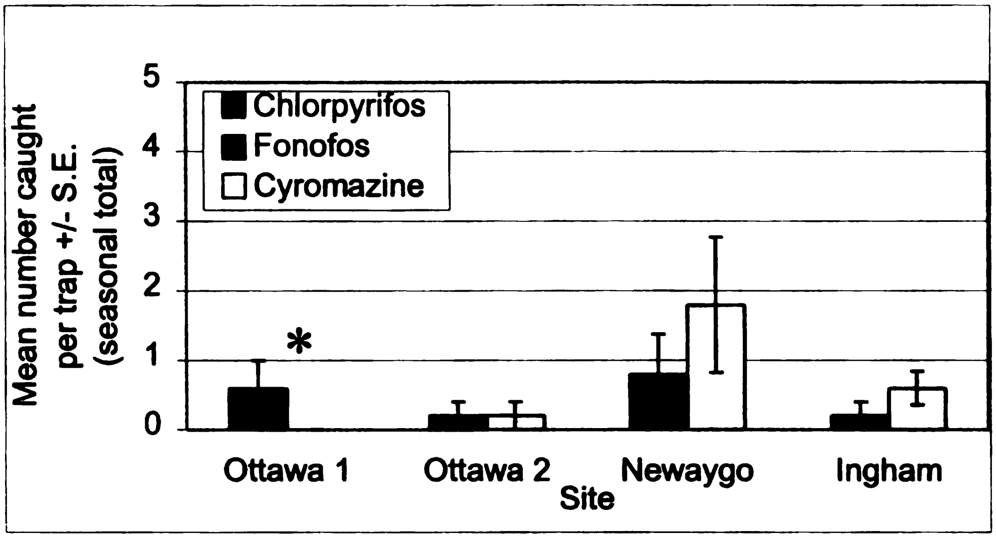


Figure 11. Number of *Clivinia impressifrons* caught per trap per week in chlorpyrifos and cyromazine treatments in four different onion field sites in 1997.

(= chlorpyrifos, = cyromazine, | = insecticide spray)

A. 1996



B. 1997

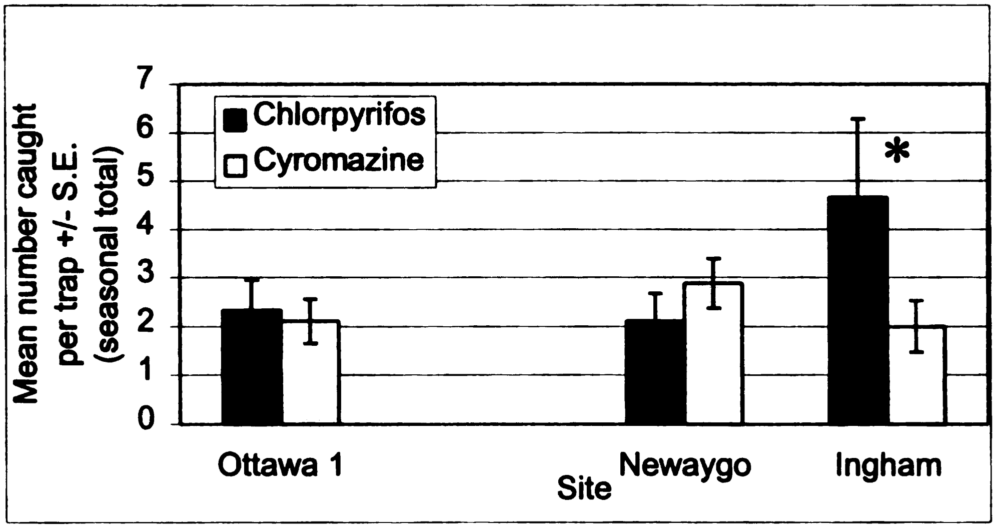
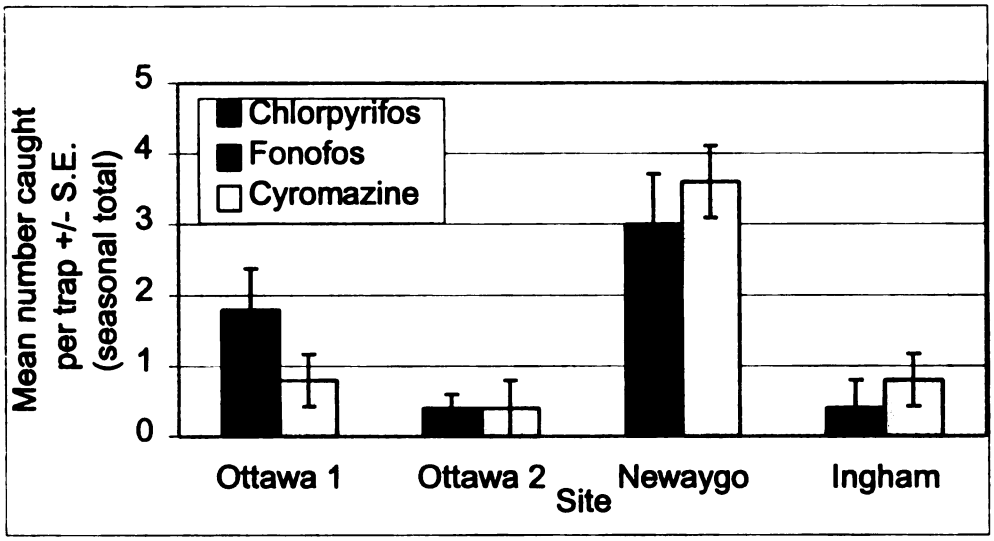


Figure 12. Total numbers of *Stenolophus comma & lecontei* caught per trap in chlorpyrifos and cyromazine treated areas located in four different onion field sites during the 1996 and 1997 growing seasons. (Poisson means = variance; * =significantly different, $p<0.05$)

A. 1996



B. 1997

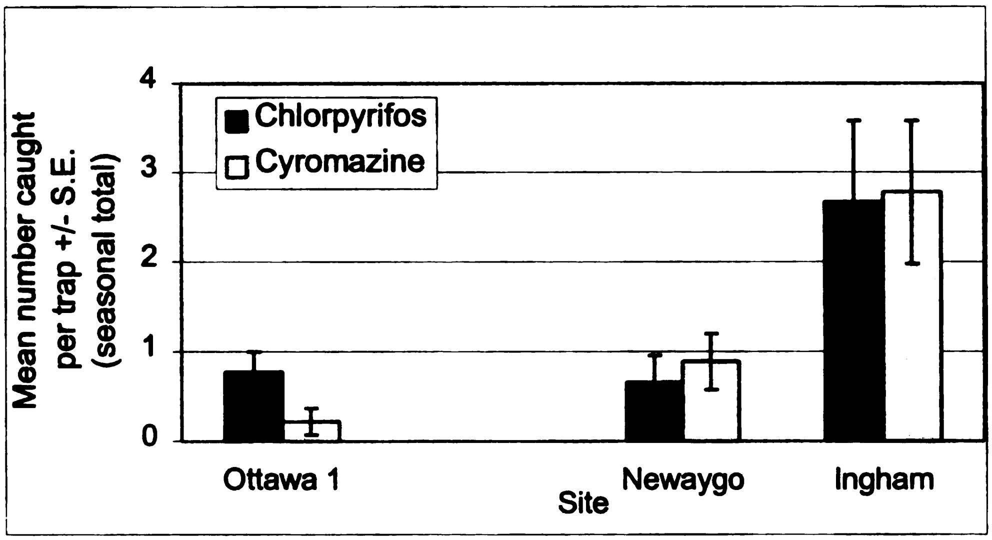
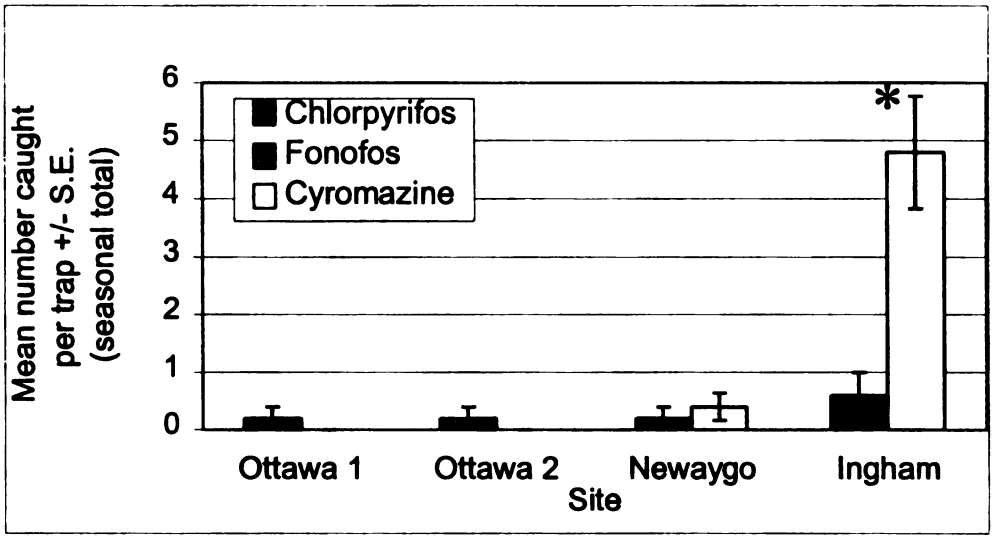


Figure 13. Total numbers of *Poecilus lucublandus* caught per trap in chlorpyrifos and cyromazine treated areas located in four different onion field sites during the 1996 and 1997 growing seasons.

(Poisson means = variance; * =significantly different, p<0.05)

A. 1996



B. 1997

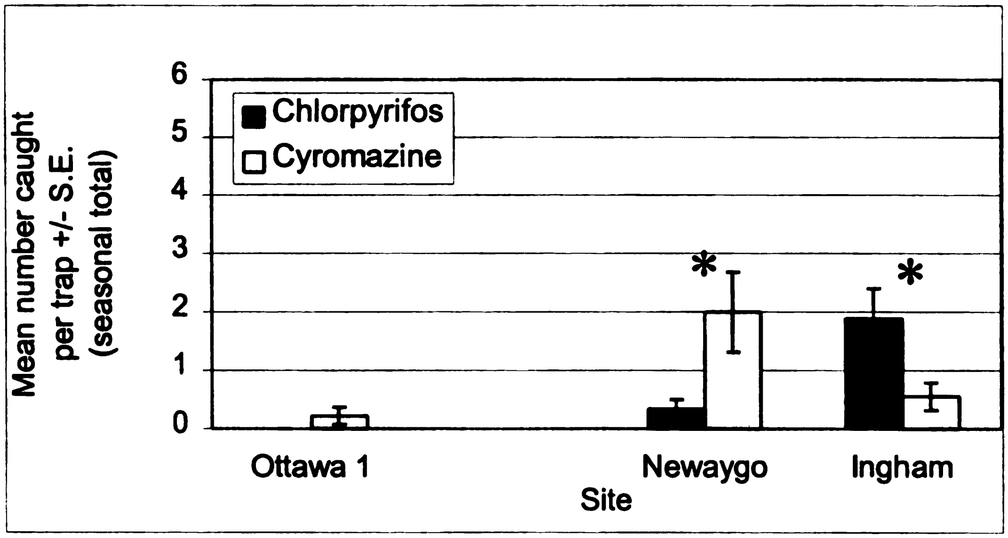
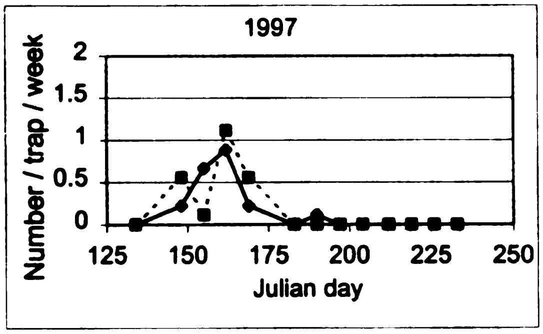


Figure 14. Total numbers of *Bembidion quadrimaculatum* caught per trap in chlorpyrifos and cyromazine treated areas located in four different onion field sites during the 1996 and 1997 growing seasons.

(Poisson means = variance; * =significantly different, $p<0.05$)

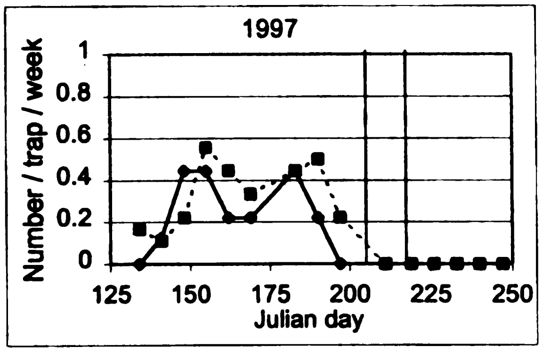
A. Ottawa 1



B. Ottawa 2

None caught

C. Newaygo



D. Ingham

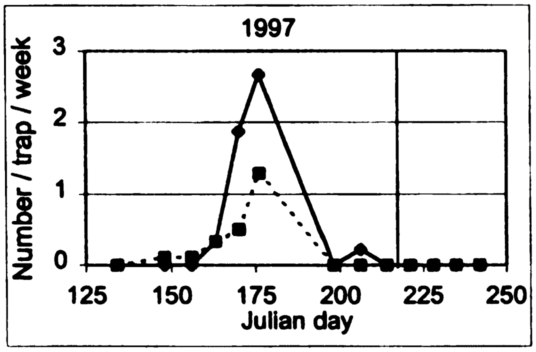


Figure 15. Number of *Stenolophus comma* & *lecontei* caught per trap per week in chlorpyrifos and cyromazine treatments in four different onion field sites in 1997.

(= chlorpyrifos, = cyromazine, | = insecticide spray)

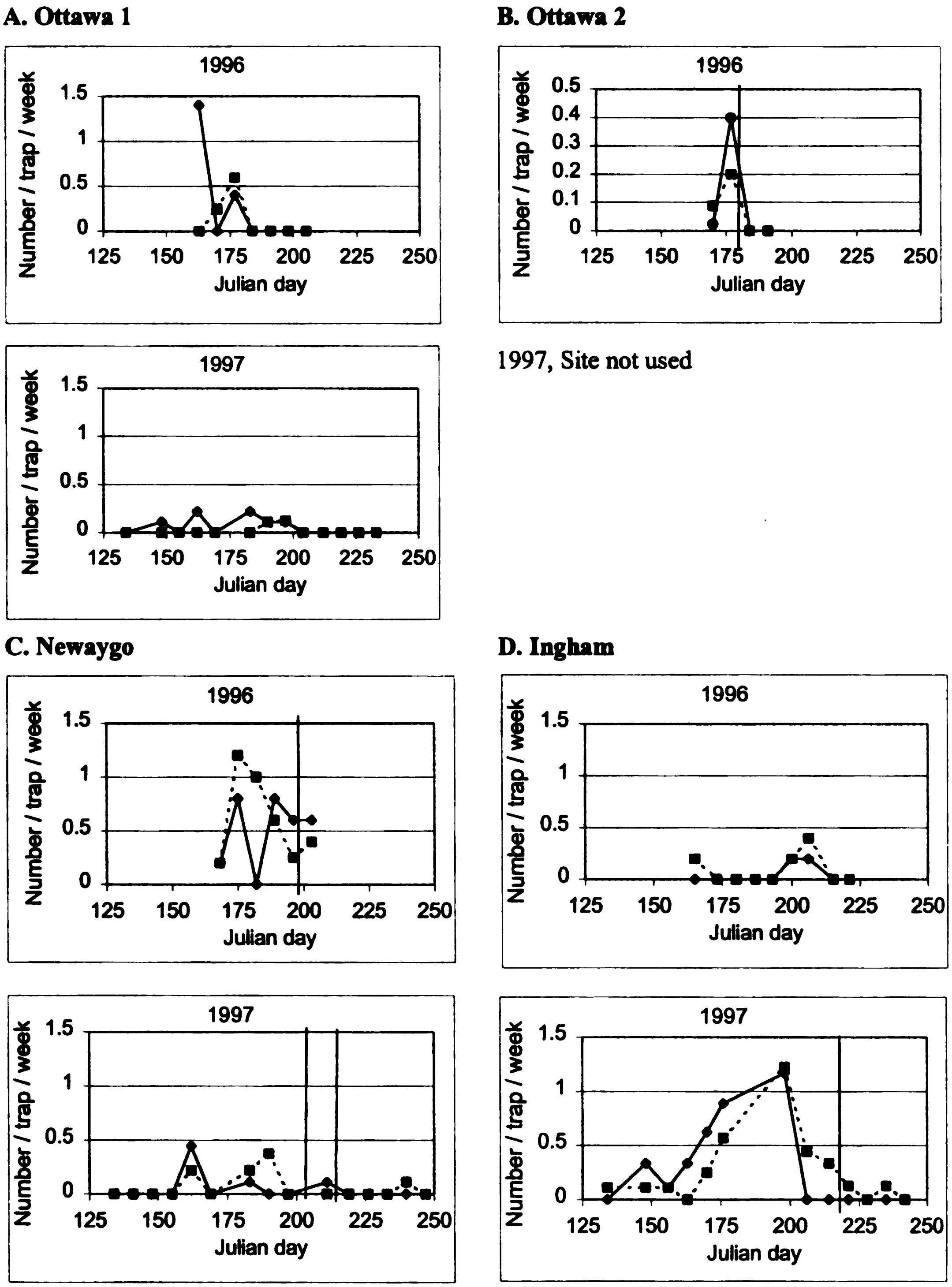


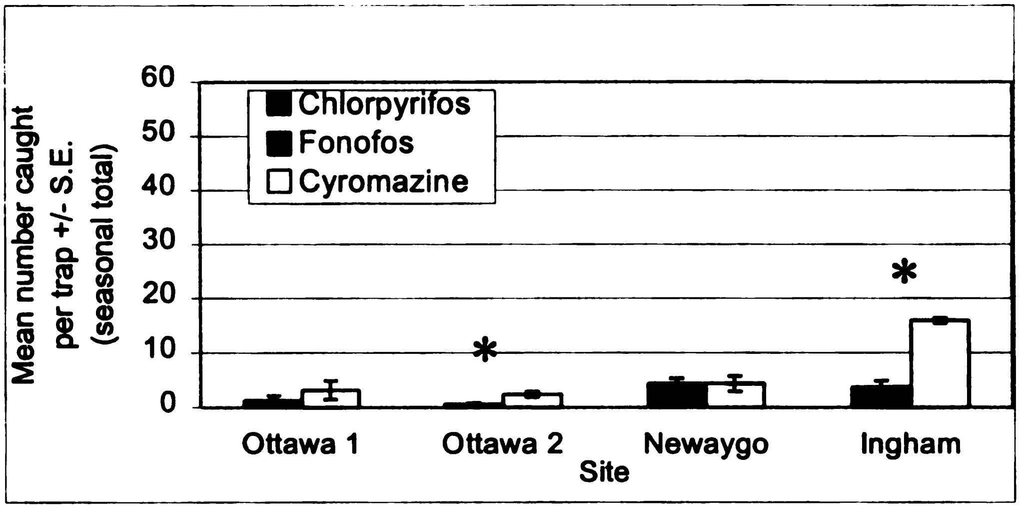
Figure 16. Number of *Poecilus lucublandus* caught per trap per week in chlorpyrifos and cyromazine treatments in four different onion field sites in 1996 and 1997. (◆ = chlorpyrifos, ● = fonofos, ■ = cyromazine, | = insecticide spray)

Staphylinids. In 1996, staphylinids were significantly more numerous in the cyromazine treated area than in chlorpyrifos treated area at the Ingham site. At the Ottawa 2 site there were more staphylinids in the cyromazine treated area than in the fonofos treated area.(Figure 17). Moreover, in 1997 they were significantly more numerous in the cyromazine treated areas than in the chlorpyrifos treated areas in all three sites. The activity peaks during the season are composed of many different species and differ between years and fields (Figure 18).

Other arthropods. Table 4 lists some of the other organisms that were found in the pitfall traps. The numbers of organisms such as weevils, elaterids, grasshoppers and crickets do not differ regularly nor much between the two areas of the fields sampled. Even though all the chlorpyrifos traps were on one side of the field and all the cyromazine traps on the other, there does not appear to be a large difference in the numbers or taxonomic composition of other arthropods.

Anthicids. In 1996, Anthicidae (Coleoptera) were more numerous in the chlorpyrifos areas than in the cyromazine areas in two sites, more numerous in the cyromazine than in the chlorpyrifos at the Ottawa 2 site, and in equal numbers in both cyromazine and chlorpyrifos in the fourth site (Figure 19). The timing of peak activity varied between years and sites (Figure 20). However, in 1997 anthicids were more numerous in the chlorpyrifos areas at all three sites than in the cyromazine areas. Anthicids are small beetles that are found in many locations and habitats. Adults of many species are found in association with decaying vegetation on the surface of the ground. Adults are probably omnivorous (Young 1991) though some are predacious with reports of attack on mites, scales or other small invertebrates on cotton and pine vegetation

A. 1996



B. 1997

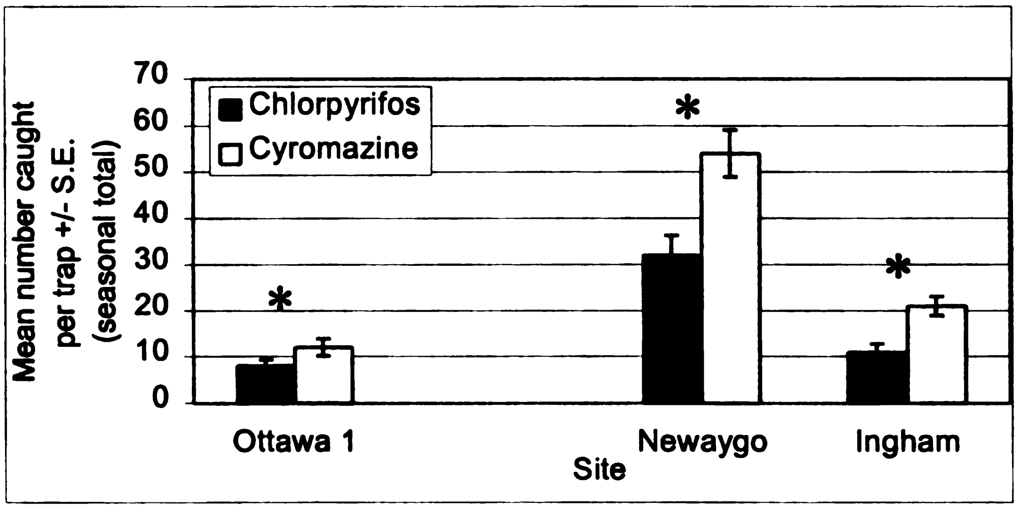


Figure 17. Total numbers of all staphylinids caught per trap in chlorpyrifos and cyromazine treated areas located in four different onion field sites during the 1996 and 1997 growing seasons.

(Poisson means = variance; * =significantly different, p<0.05)

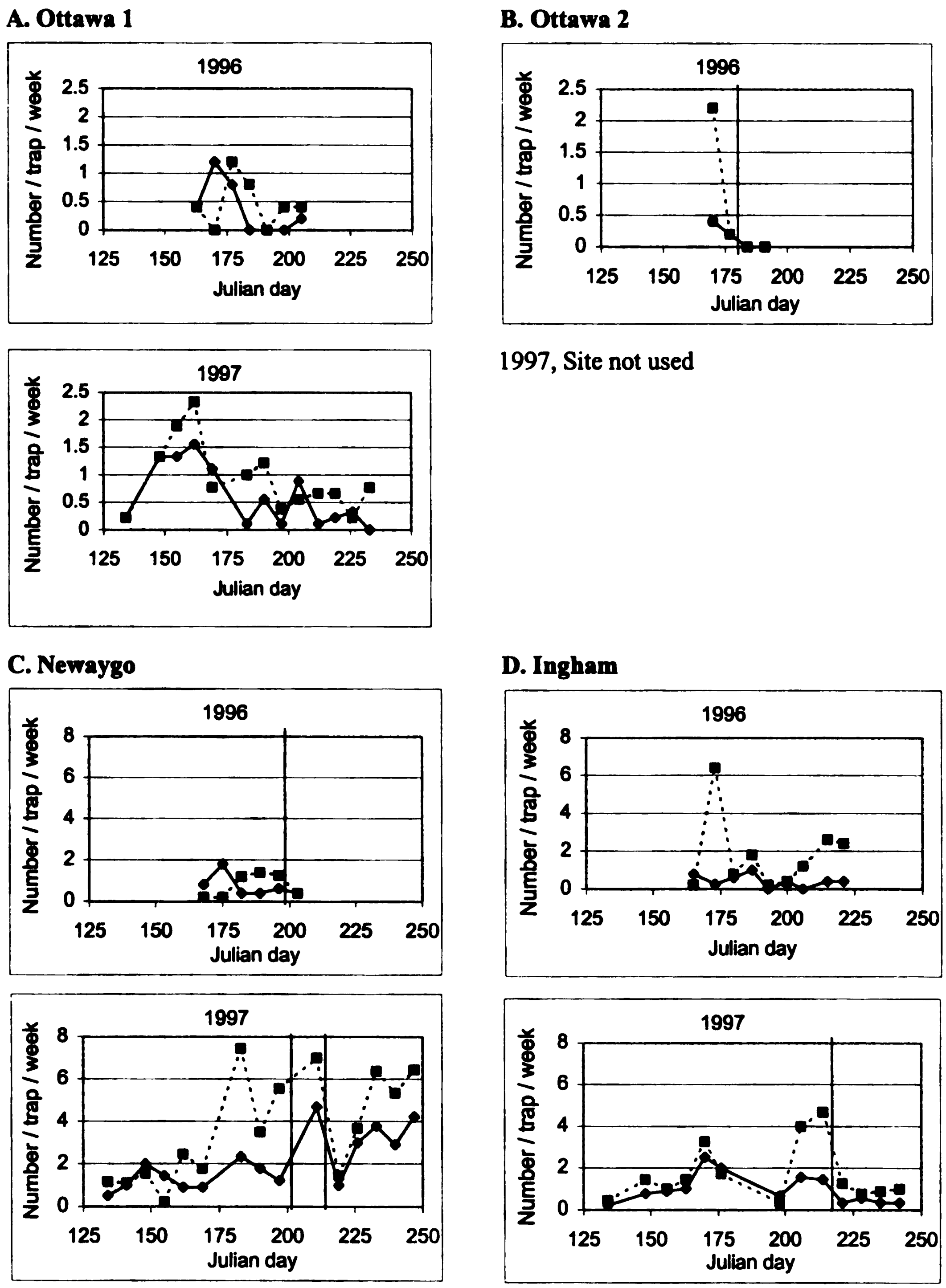


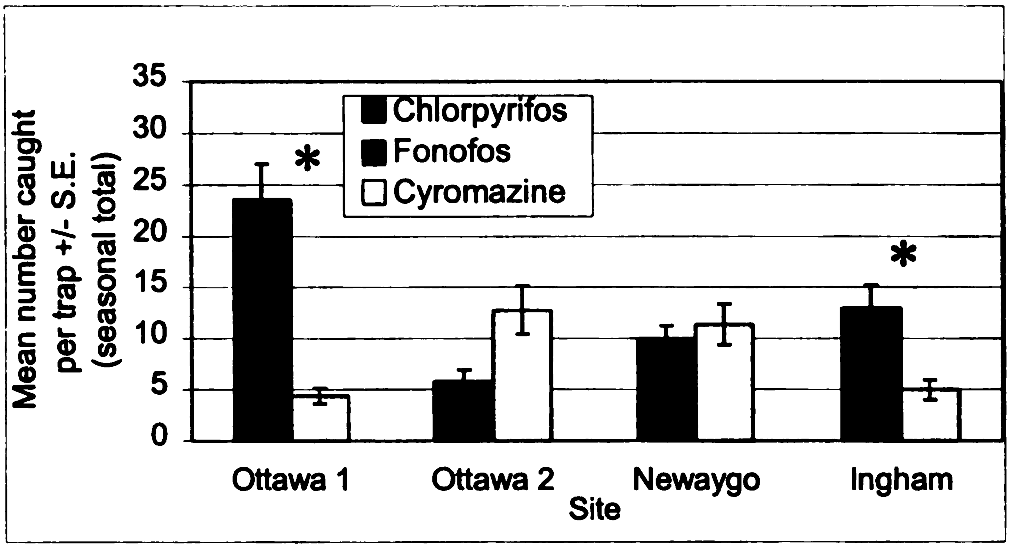
Figure 18. Number of all staphylinids caught per trap per week in chlorpyrifos and cyromazine treatments in four different onion field sites in 1996 and 1997.

(—◆— = chlorpyrifos, —●— = fonofos, ··■·· = cyromazine, | = insecticide spray)

Table 4. Total number of selected non-carabids caught in all traps per insecticide treatment over the entire trapping time, A=chlorpyrifos, B=cyromazine, C=fonofos

	Ottawa 1				Ottawa 2		Newaygo				Ingham			
	1996		1997		1996		1996		1997		1996		1997	
Species	A	B	A	B	C	B	A	B	A	B	A	B	A	B
other anthicid species	29	13	200	145	26	52	27	21	186	144	41	25	156	81
Notoxus sp.	89	9	3	1	3	12	23	36	4	7	4	1	105	20
Total Anthicidae	**118**	**22**	**203**	**146**	**29**	**64**	**50**	**57**	**190**	**151**	**45**	**26**	**261**	**101**
Araneae (Spiders)	45	103	86	127	43	22	43	49	103	126	187	228	57	89
Opiliones (Harvestmen)	-	-	1	2	-	-	-	-	7	9	-	-	1	6
Aeolus mellillus	10	14	29	22	15	28	8	10	3	6	60	62	19	12
Other spp.	0	0	3	7	8	5	8	7	3	10	3	18	7	39
Total Elateridae	**10**	**14**	**29**	**22**	**15**	**28**	**8**	**10**	**3**	**6**	**60**	**62**	**19**	**12**
Coleomegilla maculata	9	2	33	26	1	2	17	14	34	30	10	2	69	55
Coccinella septumpunctata	-	-	8	17	0	0	5	0	62	112	0	0	12	7
Hippodamia sp.	0	3	5	15	0	0	1	3	83	84	0	1	34	17
Total Coccinellidae	**9**	**5**	**46**	**58**	**1**	**2**	**23**	**17**	**179**	**226**	**10**	**3**	**115**	**79**
Curculionidae	0	2	16	26	-	-	0	2	11	8	3	8	16	3
Histeridae	-	-	2	3	-	-	0	1	0	8	1	3	32	44
Nitidulidae	-	-	10	4	2	2	-	-	5	8	11	4	6	7
Siphidae: Nicrophorus	-	-	2	3	-	-	-	-	3	6	-	-	12	8
chrysopids	1	1	4	6	-	-	-	-	0	8	-	-	1	0
centipede	-	-	-	-	-	-	29	9	6	17	5	7	0	1
milipede	-	-	7	9	1	0	-	-	0	1	-	-	5	1
grasshoppers	4	8	-	-	1	1	1	1						
crickets					2	0	11	8	-	-	5	4	-	-
earthworm	1	0	3	2	-	-	8	8	32	84	-	-	0	3

A. 1996



B. 1997

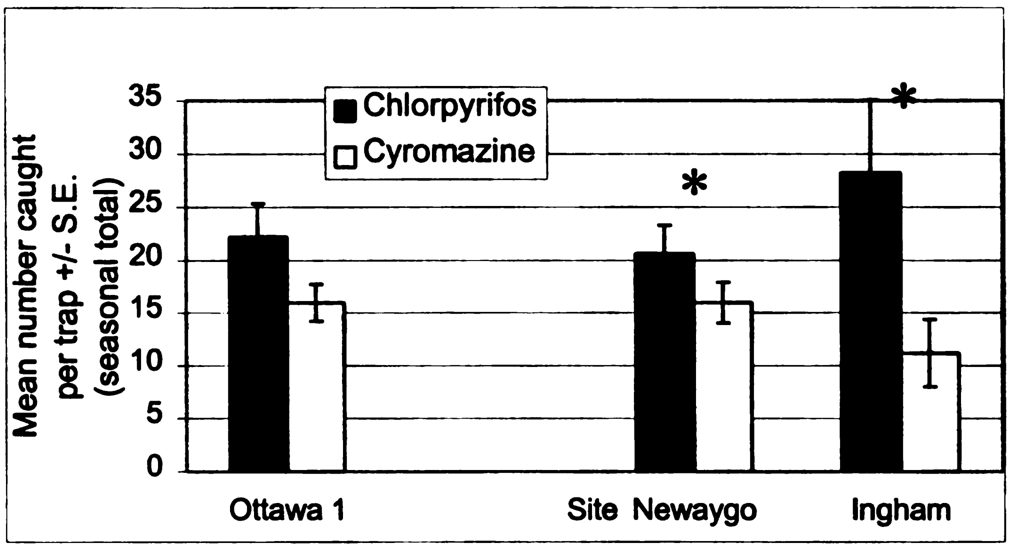


Figure 19. Total numbers of all anthicids caught per trap in chlorpyrifos and cyromazine treated areas located in four different onion field sites during the 1996 and 1997 growing seasons.

(Poisson means = variance; * =significantly different, $p<0.05$)

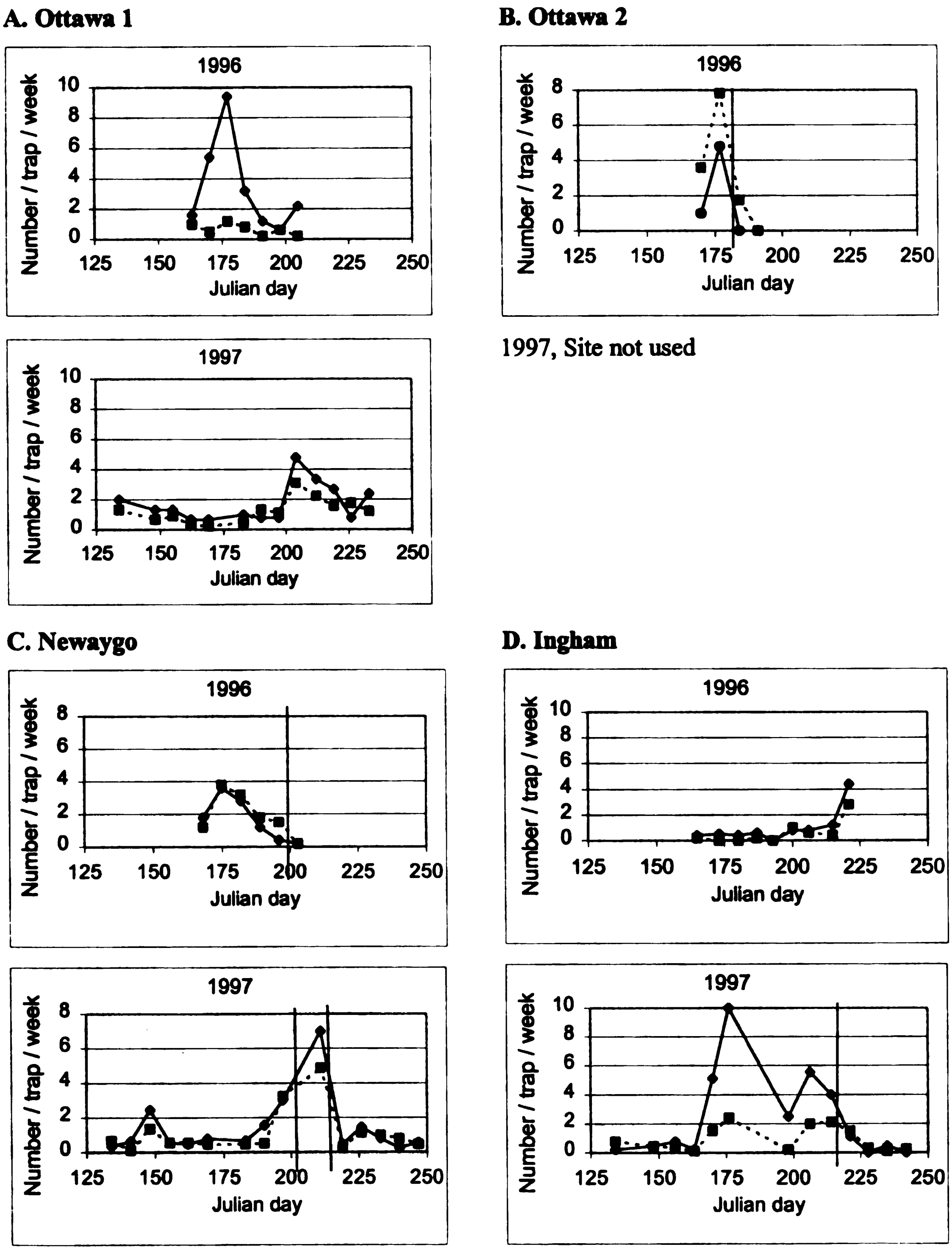


Figure 20. Number of anthicids caught per trap per week in chlorpyrifos and cyromazine treatments in four different onion field sites in 1996 and 1997.

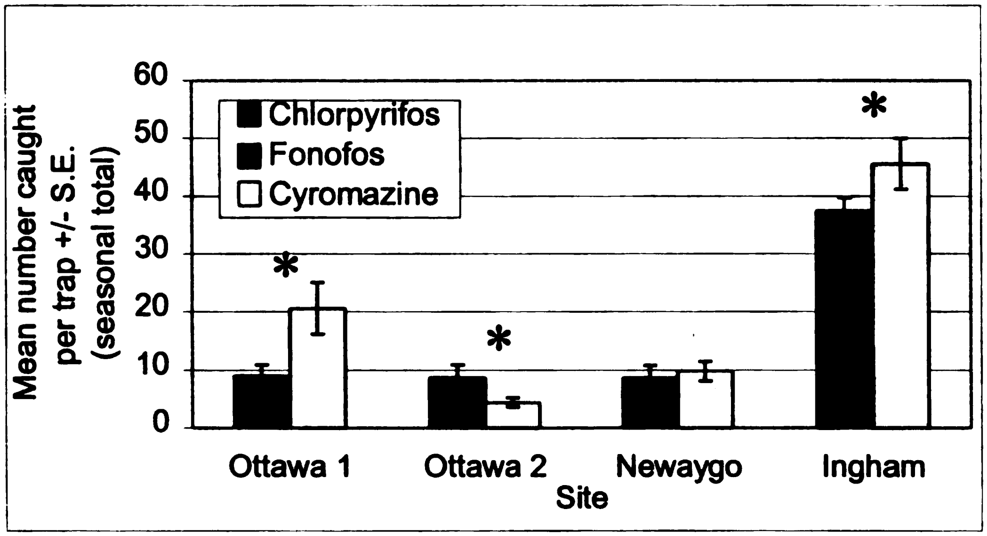
(= chlorpyrifos, = fonofos, . = cyromazine, = insecticide spray)

(Werner & Chandler 1995). Larvae are generally associated with decaying vegetative materials where most are omnivorous or mycetophagous; there are a few reports of anthicids feeding on insect eggs and pupae (Young 1991). In this study, the anthicids were frequently observed on the soil surface, but never on the onion plants. Motyka & Edens (1984) collected an *Anthicus* sp. consistently in Michigan onion fields, but never in large numbers; they noted a peak of activity in August.

Spiders. There were more spiders in the fonofos area than in the cyromazine treated area at the Ottawa 2 site in 1996; at the two other sites there were more spiders in the cyromazine treated areas than in the chlorpyrifos treated areas (Figure 21-22). This pattern continues into 1997 with more spiders in the cyromazine treated areas and chlorpyrifos treated areas at Ottawa 1 and Ingham sites. There appeared to be the most spider activity in the middle of the season (Figure 22).

Coccinelids. *Coleomegilla maculata* (DeG.) was significantly more numerous in the chlorpyrifos treated area than in the cyromazine area in two sites in 1996 (Figure 23). In 1997, there were no significant differences between treatments, however there appeared to be a trend of more *C. maculata* in the chlorpyrifos areas than in the cyromazine areas. No pattern of relative abundance appears in Figure 24 for *Coccinella septumpunctata* (L.). The *Hippodamia* spp. were more numerous in cyromazine areas at two sites in 1997, but at other sites the species was not common or was of the same abundance in both treatments (Figure 25).

A. 1996



B. 1997

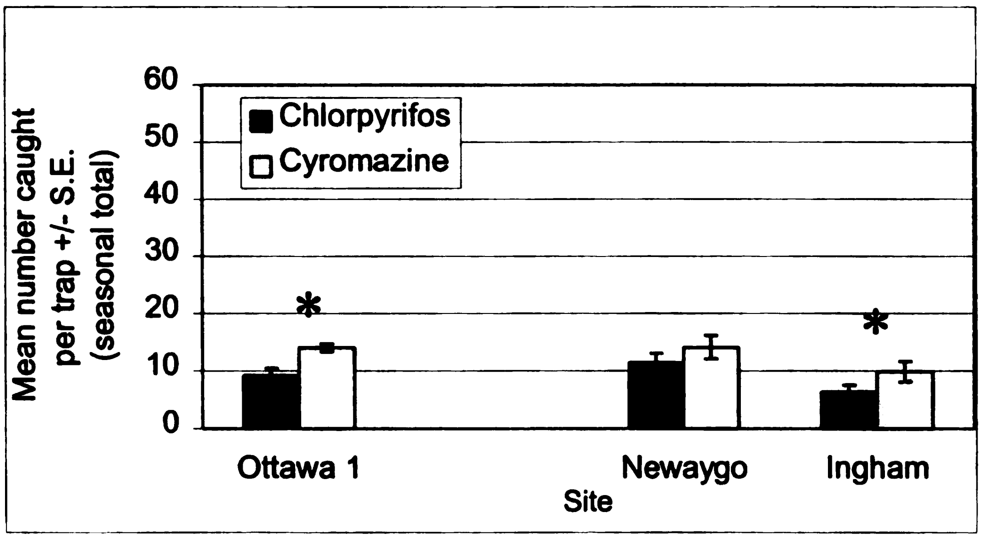


Figure 21. Total numbers of all spiders caught per trap in chlorpyrifos and cyromazine treated areas located in four different onion field sites during the 1996 and 1997 growing seasons.

(Poisson means = variance; * =significantly different, p<0.05)

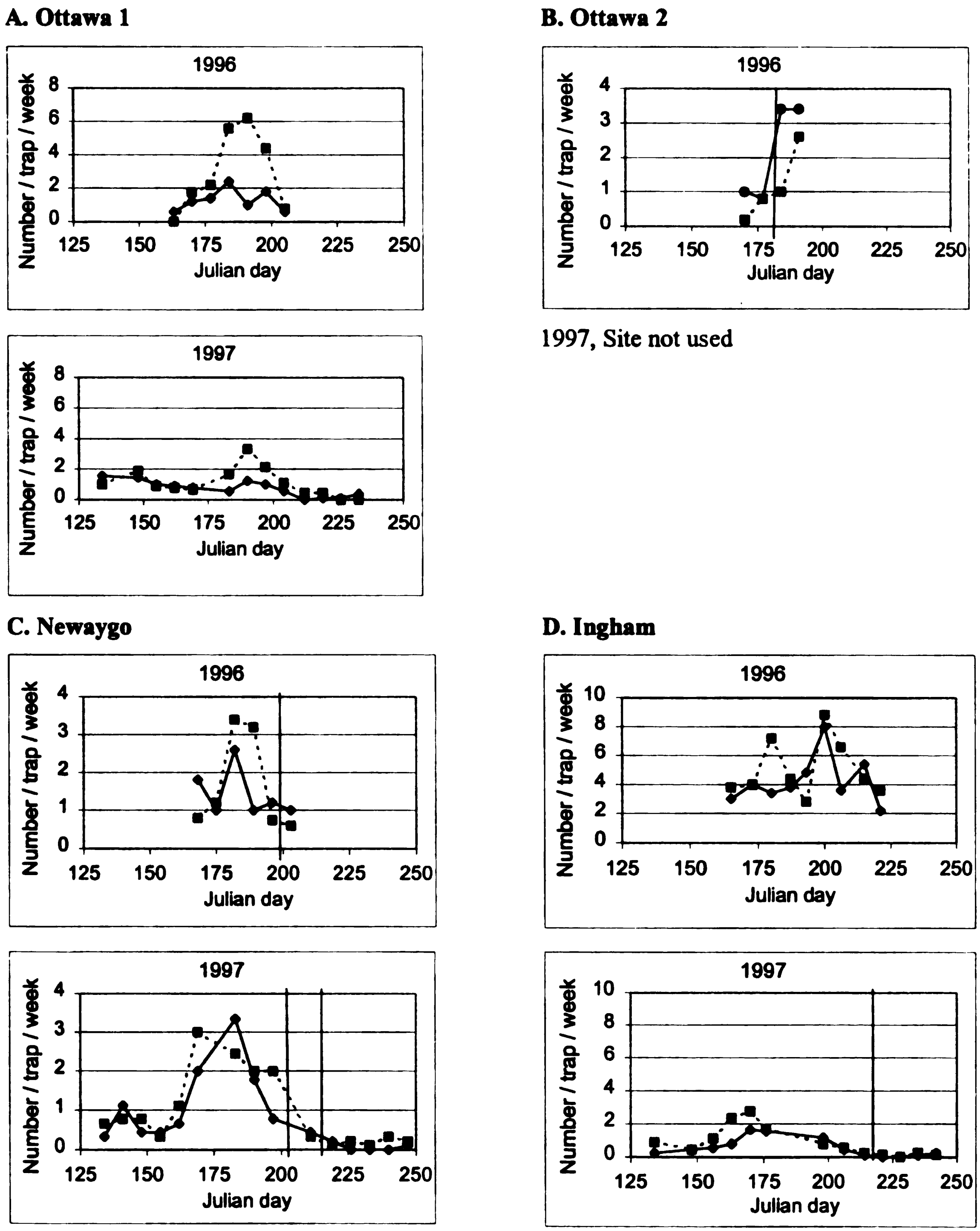
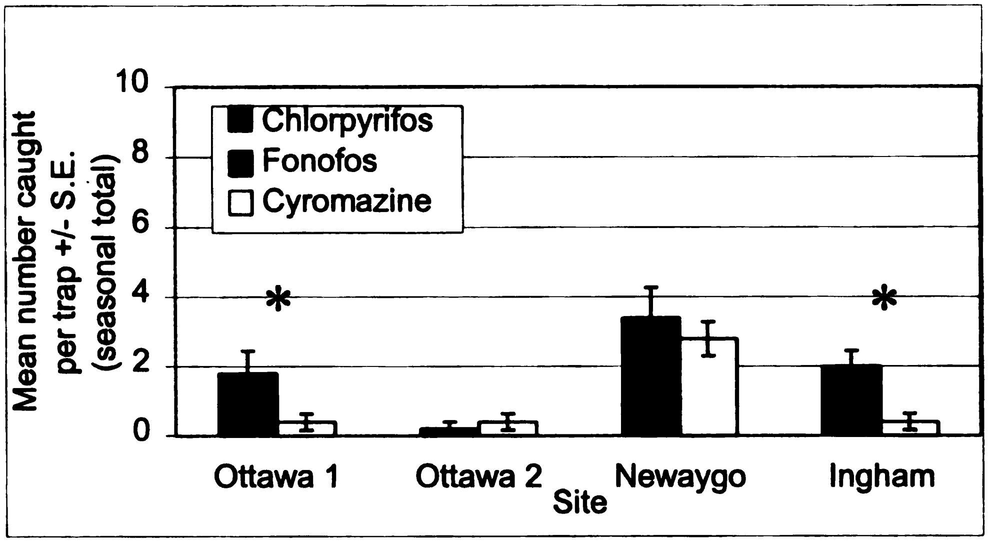


Figure 22. Number of spiders caught per trap per week in chlorpyrifos and cyromazine treatments in four different onion field sites in 1996 and 1997.

(◆ = chlorpyrifos, ● = fonofos, ■ . = cyromazine, | = insecticide spray)

A. 1996



B. 1997

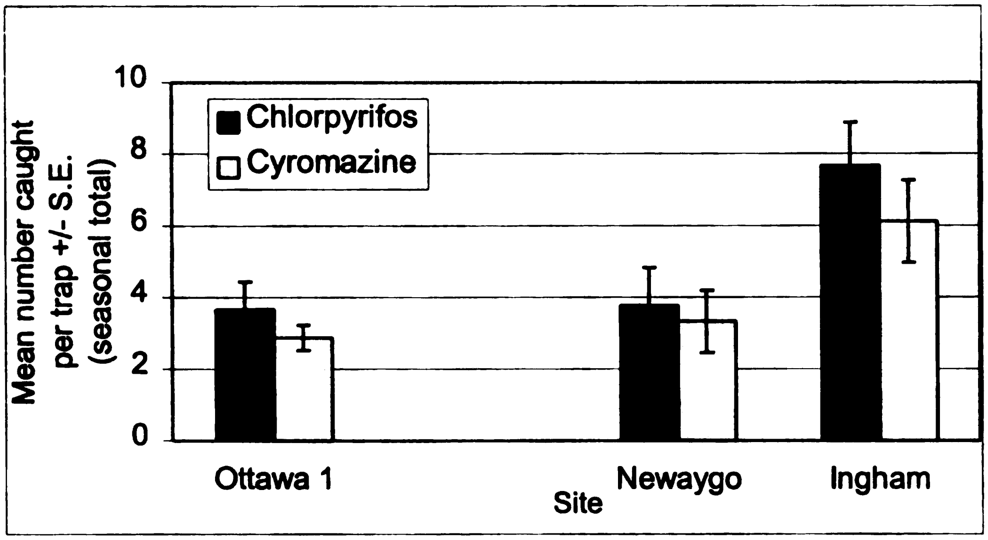
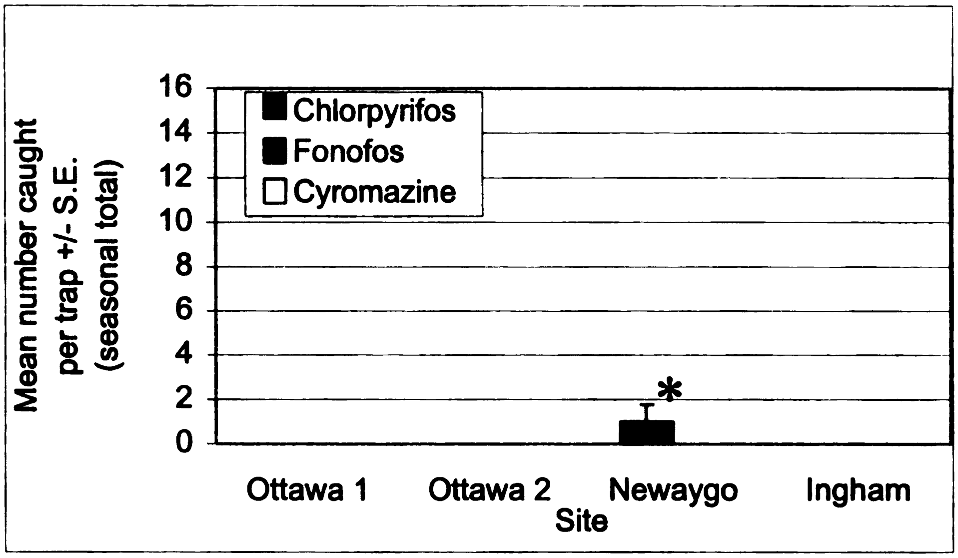


Figure 23. Total numbers of *Coleomegilla maculata* caught per trap in chlorpyrifos and cyromazine treated areas located in four different onion field sites during the 1996 and 1997 growing seasons. (Poisson means = variance; * =significantly different, $p<0.05$)

A. 1996



B. 1997

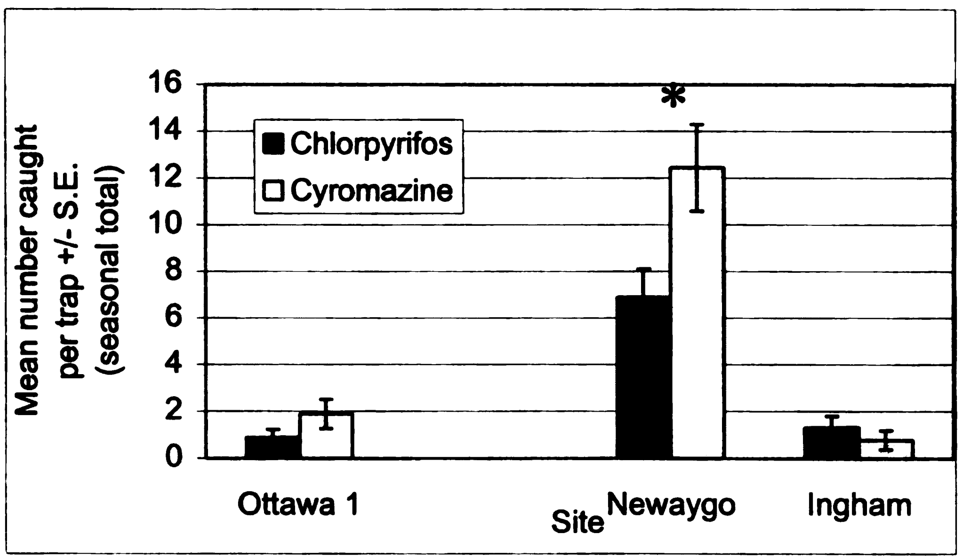
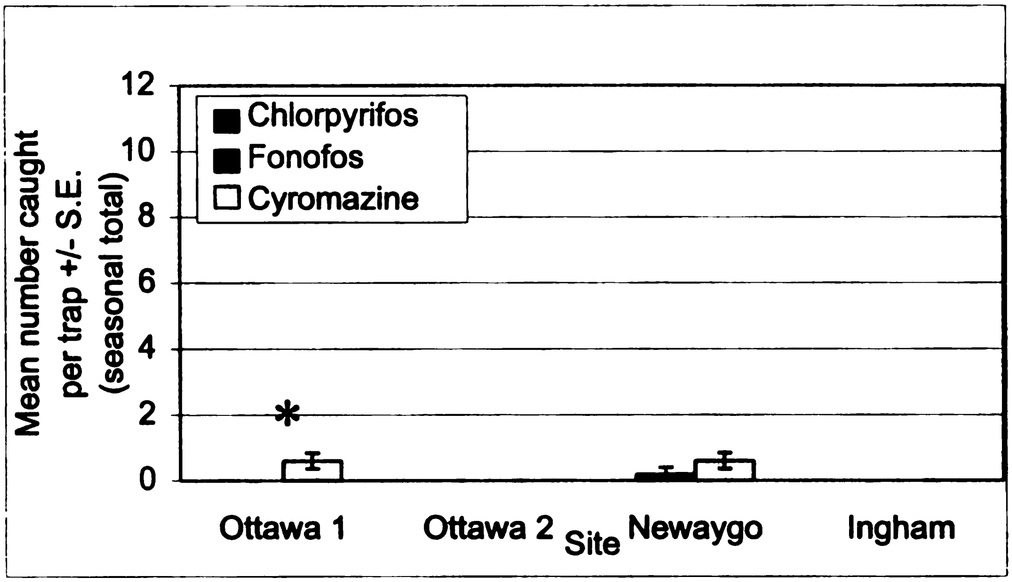


Figure 24. Total numbers of *Coccinella septumpunctata* caught per trap in chlorpyrifos and cyromazine treated areas located in four different onion field sites during the 1996 and 1997 growing seasons. (Poisson means = variance; * =significantly different, p<0.05)

A. 1996



A. 1997

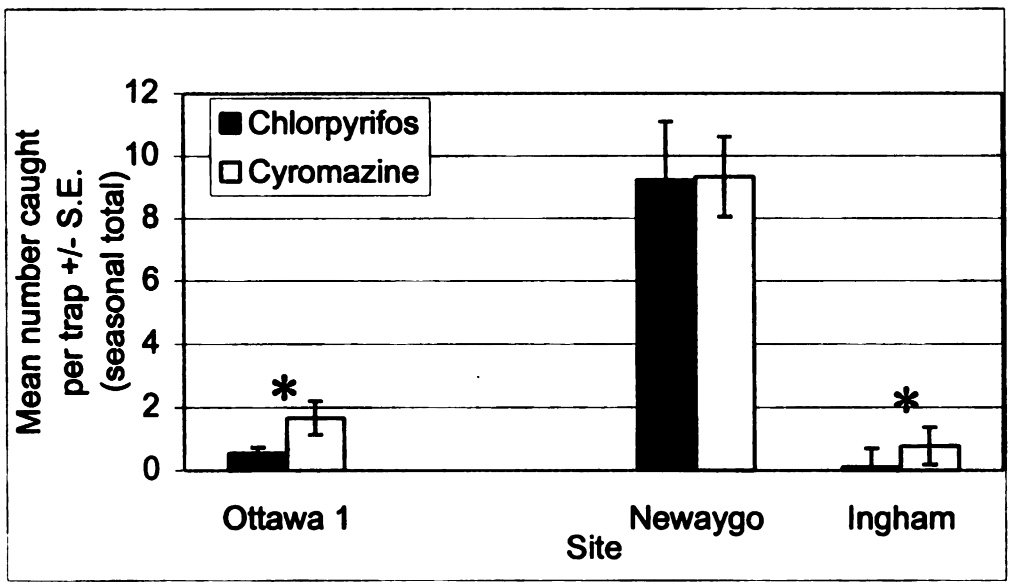


Figure 25. Total numbers of *Hippodamia* spp. caught per trap in chlorpyrifos and cyromazine treated areas located in four different onion field sites during the 1996 and 1997 growing seasons.

(Poisson means = variance; * =significantly different, $p<0.05$)

Figure 26 shows the relative numbers of the most common carabid species. When *P. chalcites* was the most common species, carabids as a group were more numerous in the cyromazine areas. However, *A. sanctaecrusis*, was the most numerous at the Ingham site in 1997 and its numbers did not appear to be decreased by chlorpyrifos, although the total number of carabids was reduced. *P. melanarius* was the most common species at the Newaygo site and appeared to be less numerous in the chlorpyrifos area and reduced the total number of carabids caught.

Conclusions

There is some question as to the reliability of pitfall traps for assessing the impact of pesticides on populations of ground-dwelling arthropods. Edwards and Thompson (1975) found that the neurologically active insecticides cause hyperactivity that enhances catches in sprayed plots relative to unsprayed ones and that pitfall catches are influenced by beetle immigration. Chiverton (1984) concluded that reducing prey populations by the application of insecticides results in hungrier carabid beetles with consequently higher activity. Since pitfall trap catches are determined not only by population size but also activity, he argues that, "pitfall-trap catches alone cannot give a true measure of the effects of insecticides on carabid populations in the field." In a peanut field, Dixon & McKinlay (1992) hypothesized that after being sprayed with insecticide, the pests (aphids) fall off plants. The beetles then ate the aphids and were less hungry, therefore, less active and less likely to be trapped; later increases in catches may have been due to hungry and thus more active beetles. In the onion system, the availability of eggs or maggots, which are already on or in the ground, is probably not increased due to the insecticides. Floate et al. (1989) found the toxicity of chlorpyrifos on *Bembidion* species much higher in the

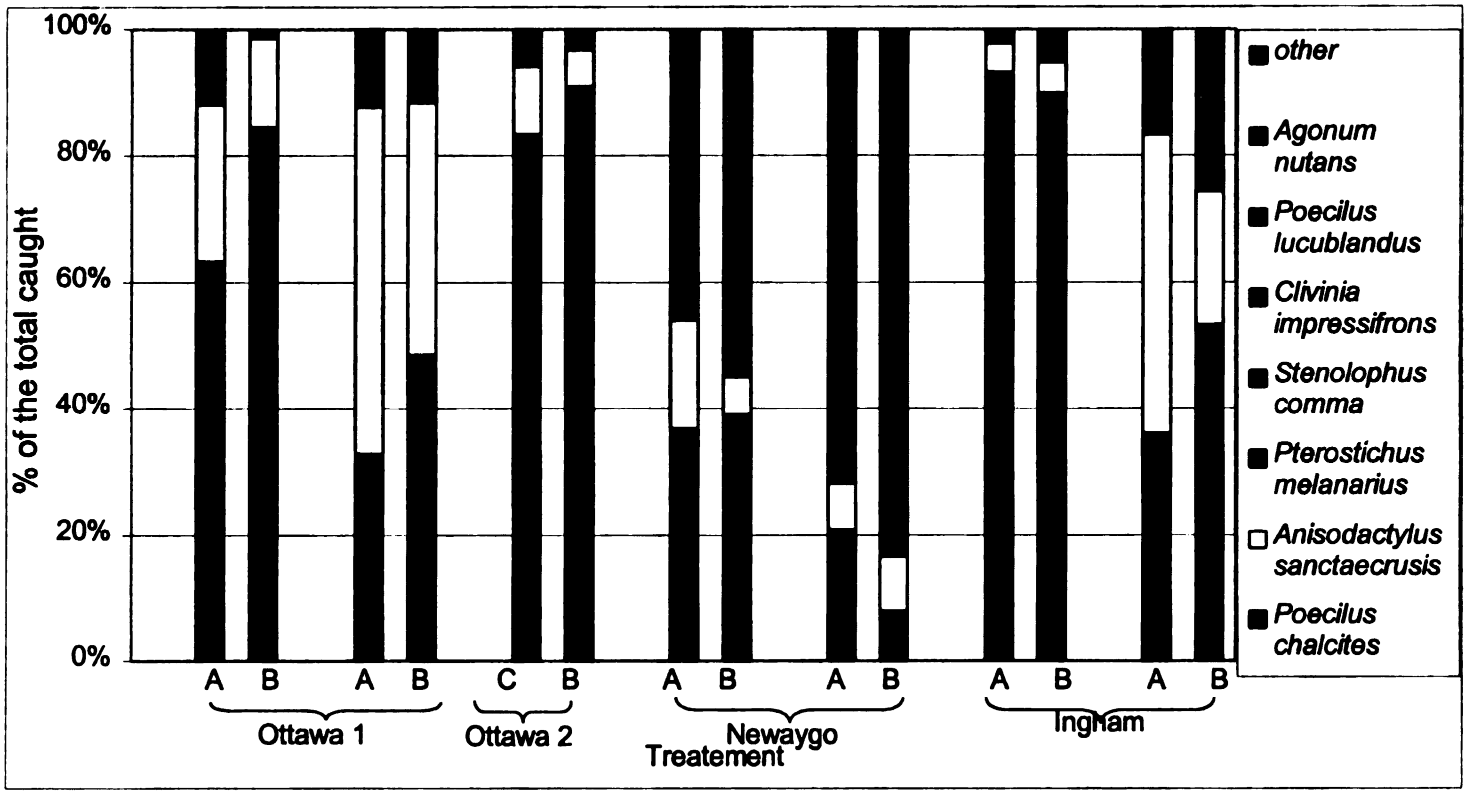


Figure 26. Composition of the carabid populations in chlopyrifos (A), cyromazine (B), and fonfofos (C) at four farms in 1996 and 1997.

laboratory than in the field and suggested that adult immigration and residual toxicity influence pitfall catches and recovery of carabid populations after spraying. These arguments against the use of pitfall traps except Dixon and McKinley (1992), result from higher numbers of carabids caught in sprayed areas.

In the present experiment, cyromazine is compared to chlorpyrifos. Cyromazine, which affects larvae, should not directly cause adult carabid mobility. The first year data showed that if there was a difference in trap catches between treatments, the number of carabids or staphylinids caught were lower in chlorpyrifos than in the cyromazine treated area. Therefore, while not perfect, pitfall traps seemed adequate and were used in the second year of the experiment.

The total number of carabids was nearly always higher in the cyromazine areas than in the chlorpyrifos areas, but each of the species that made up the carabid population exhibited its own relative abundance. Insecticides are known to produce differential kills of ground beetles when applied at equal concentrations (Mowat & Coaker 1967, Critchely 1972, Tomlin 1975, Gholson et al. 1978, Los & Allen 1983, Thiele 1997, Hassan et al. 1991). These differences might be due to physiology, behavior, or size. However, in these experiments, no species of carabid was always more numerous in the chlorpyrifos area than in the cyromazine area.

The results of this study indicate that cyromazine may be less toxic than chlorpyrifos to adult carabids, staphylinids and spiders, however, there is question about the relative effects on the immature stages of the beetles which are soil inhabiting. Bartlett (1964) generalized that it is the adult stages of predators and parasites that were the most susceptible to insecticides, while eggs the least. He thought that holometabolist larvae were intermediately susceptible and heterometabolous nymphs were more prone to be poisoned than adult forms. Tomlin (1975) using topical application found that chlorfenvinphos, an organophosphate pesticide, was fairly innocuous to carabid larvae although it had a wide range of effects upon adult carabids.

The effects of cyromazine on the immature stages of onion maggot predators have not been tested. Cyromazine, may not be Diptera specific. Cyromazine has been shown to affect Colorado potato beetle (Coleoptera: Chrysomelidae) (Sirota & Grafius 1994) and *Manduca* spp. (Lepidoptera: Sphingidae) larvae (Kotze & Reynolds 1991). Therefore, when the effects of chlorpyrifos and cyromazine on larvae are compared, the results might be different.

The introduction of an insect growth regulator into the onion system may allow increased biological control, contributing to reduced pest damage, greater pest/crop stability, and reduced risk of crop loss. These kinds of changes are essential if producers are to reduce reliance on pesticides, as is desired by environmental and consumer groups.

Carabidae predation on onion maggot *Delia antiqua* (Meigen) (Diptera: Anthomyiidae) and subsequent maggot damage to onions

ASTRACT

Trenches were used to increase and decrease existing carabid beetle densities in an onion field. The relative survival of onion plants on which maggot eggs had been placed did not differ between the high and low carabid densities. In a second experiment, the number of eggs placed in the field that survived to third instar or to pupate did not depend on the carabid concentration treatments. Reasons for the lack of treatment effects are discussed. Fewer maggots placed in the field did, however, survive in the treatments with higher carabid concentrations.

In no-choice feeding studies, carabid beetles commonly found in Michigan onion fields ate onion maggot eggs and onion maggots. Mean number of maggot eggs consumed per beetle ranged from <10 to >90 per day.

Introduction

Carabidae and Staphylinidae predation on the immature stages of *D. antiqua* (Drummond 1982, Grafius & Warner 1989, and Tomlin et al. 1985) and its relatives *Delia radicum*(Bouche) (Wishart 1959, Hughes 1959, Hughes & Salter 1959, Coaker & Williams 1963, and Coaker 1968, Mowat & Martin 1981, Uba Yaman 1990) and *Delia floralis* (Fallen) (Andersen et al. 1983) has been documented in North America and Northern Europe. Depending on the species composition in the field, these studies have estimated that these predators may eat 17-90% of the eggs laid by *D. radicum*, the cabbage maggot. Grafius and Warner (1989) reported that one species of carabid, *Bembidion quadrimaculatum* L., at high enough population densities could potentially remove 60% of *D. antiqua* eggs from the field. However, as Varis (1989) noted upon reviewing several of the studies cited above, carabids can destroy considerable number of root fly eggs, the resultant effects on crop loss are often indistinct.

The objective of this study was to determine the predatory impact of carabids and staphylinids on *D. antiqua* in an onion monoculture and subsequent impacts on the onion stand.

Methods

Field experiments. In 1998 two field experiments were done to test the impact of predators on survival of immature *D. antiqua* at the Michigan State University Muck Soils Research Farm, Clinton Co. Michigan. The soil at the farm has an organic matter content of 80%. In the spring, an experiment tested the impact of carabids on onion survival. In the late summer, when the onion tops had died back and the onions were ready to harvest a study was done to assess predation on onion maggots and on onion maggot eggs.

The field used in this experiment was 61 m long (N-S) by 15.2 m wide (E-W) consisting of 36 planting beds that were 1.2 m wide and were raised 15 cm higher than the surrounding soil with 30-45 cm between beds. An early variety onion was planted in three rows on each bed. No insecticide was used at planting nor during the course of the experiment. Within the field, 12 plots (6.1 x 6.1 m) were arranged in a randomized complete block design with four blocks of three treatments. In the three treatments the density of beetles was a) same as existing b) decreased relative to existing, or c) increased relative to existing. The altered beetle density plots were created by digging a 15 cm deep trench around each plot. In the decreased density plots, the inner walls of the trench were lined with a continuous piece of black plastic thereby permitting beetles to crawl out of but not into the plots (Wright 1960); pitfall traps were used to further reduce beetle numbers. In the increased density plots, the outer walls of the trenches were lined with plastic thereby permitting beetles to crawl into but not out of the plots. In both treatments, the upper and lower edges of the plastic were anchored every 1 m with sections of bent wire. These edges were then buried under about 3-5 cm of soil. To determine whether the three treatments resulted in significantly different beetle densities, each whole plot treatment was sampled using four pitfall traps (Figure 1).

An irrigation pipe that had pivoting heads ran lengthwise down the center of the field. The farm manager irrigated the field in the mornings when necessary. Each whole plot had one edge of the treatment bordering the pipe (Figure 2).

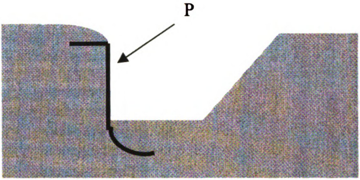


Figure 1. Cross-section through trench around plot showing the plastic sheeting (P) that restricts beetle movement.

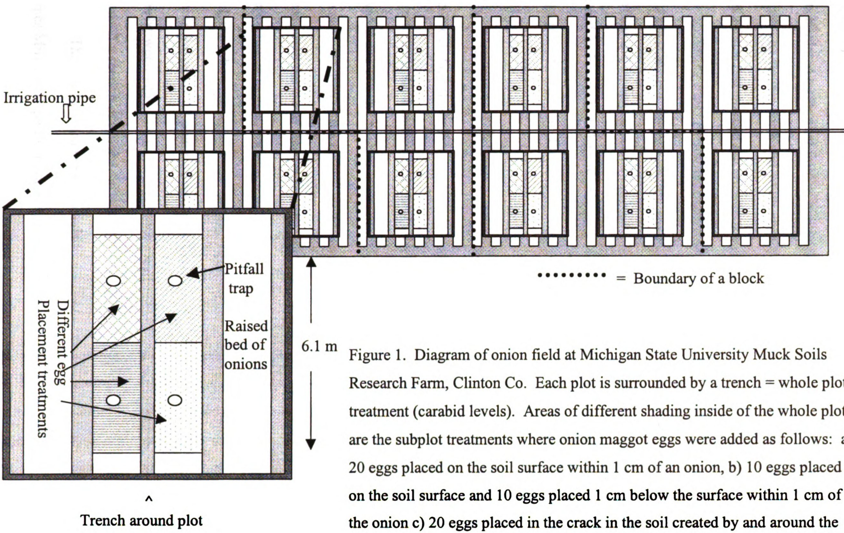


Figure 1. Diagram of onion field at Michigan State University Muck Soils Research Farm, Clinton Co. Each plot is surrounded by a trench = whole plot treatment (carabid levels). Areas of different shading inside of the whole plot are the subplot treatments where onion maggot eggs were added as follows: a) 20 eggs placed on the soil surface within 1 cm of an onion, b) 10 eggs placed on the soil surface and 10 eggs placed 1 cm below the surface within 1 cm of the onion c) 20 eggs placed in the crack in the soil created by and around the base of the onion plant d) no eggs placed (control).

All sides of the field were bordered by 4 m bare soil. Beyond the bare soil, the west side was bordered by another field of onions and the east wide was bordered by a field of mint. The shorter north and south ends bordered respectively a thick hedgerow of shrubs, and a fence that marked the edge of the cultivated area and the start of weeds and trees

Spring Field Predation Experiment. Four subplot treatments were as follows a) 20 eggs placed on the soil surface within 1 cm of an onion, b) 10 eggs placed on the soil surface and 10 eggs placed 1 cm below the surface within 1 cm of the onion c) 20 eggs placed in the crack in the soil created by and around the base of the onion plant d) no eggs placed (control). Treatments were applied to the 25th onion from the center of the plot.

Three weeks after the trenches were put in the field and the onions had reached the 2 leaf stage the onion maggot eggs were placed on onions in the plots. To reduce edge effects, the 4 subplot treatments were applied to the inner two raised beds each divided into two 2.7 m sections with the outer 30 cm of each bed not included. In each of the subplots, two of the three rows of onions were chosen at random and any onions that were not in the 2 leaf stage were removed. Onions in a randomly-selected 1 m of a row were counted to measure initial stand. A 50 plant section of onions was marked by stakes with the following restrictions: no gaps between onions greater than 15 cm, no gaps within the center 17 plants of onions greater than 10 cm, the entire length of the section was between 125-170 cm. These restrictions were used to standardize the rows of onions used. If a section of onions did not meet the criteria, a different 1 m of onions was used.

The eggs and maggots were obtained from the culture maintained in the lab of Dr. James Miller at Department of Entomology, Michigan State University. Before being placed in the field, the eggs were counted in an air-conditioned room. Ten or 20 eggs were counted out in the lab with a watercolor brush and placed in 6 cm sections of clear plastic drinking straws. The straw ends were folded over and taped shut. Egg counting was finished at mid-afternoon, and the straws with eggs were placed in a cooler and transported to the field. The eggs were removed from the opened straws with a 2 ml burst of water from an oral syringe and the placement of the eggs was checked to be sure the eggs were within 1 cm of the plant base. The eggs were placed in the field between 6 and 9 p.m. to simulate natural timing of oviposition (Perron & LaFrance 1960).

The beetle populations were monitored via live pitfall traps (11 cm dia., 14 cm deep) located within each subplot. The pitfall traps were made out of two plastic containers. The outer container remained in the soil for the duration of the experiment and limited soil disruption when traps were checked. Traps were opened for 24 h and then the contents collected. On May 15, the contents of the depressed beetle density plots were moved to the increased plots. On May 29, the day the eggs were placed on the onions, the beetles were returned to the area sampled. On June 19 the beetles were removed and placed in alcohol.

Onion survival was counted on June 19 and August 28 (harvest time). Carabid and staphylinid numbers were log (count+1) transformed and then analyzed to determine whether whole plot treatments were statistically significant (PROC GLM, SAS Institute 1994). Ratios of onions that survived to original number counted were calculated, arcsine converted, and then analyzed as a splitplot random complete block design using PROC GLM (general linear model) ANOVA (SAS Institute 1994). Arithmetic means are used in the result section figures.

Late Summer Field Experiment. In late summer, the black plastic trenches around the plots were inspected and mended where needed. Plastic food grade containers (11 cm diam. and 14 cm deep) with two 0.5 cm holes covered with plastic screening in the bottom were filled to the rim with muck soil. The soil had been sieved to remove most insects and other visible arthropods. In each plot, two of these containers were buried so that their rims were covered with soil. A 5 cm diam. onion with its basal plate cut off was placed cut end down into a 2 cm deep depression in the soil in the center of the container. Seven second and third instar *D. antiqua* were placed under one of the onions. Twenty onion maggot eggs were placed on the side of the onion at the point where the onion met the soil so that half the eggs were above ground and half were below.

After 3 weeks, the containers with maggots added were removed. After 4 weeks the containers where the maggots eggs were placed were removed. The onions were dissected and the soil in the cup sieved and carefully inspected for onion maggots and pupae.

In addition, in each increased beetle density plot two more containers of soil were added. One had the same placement of eggs, and the other the same placement of maggots as above. However, these containers were only buried halfway into the soil. Therefore the onion and *D. antiqua* were approximately 5 cm above the soil surface and protected from predators. Each container was paired with its fully buried counterpart and the numbers of onion maggots found at the end of the experiment statistically analyzed with a paired t-test.

Pitfall traps, arranged as in the spring experiment, were used to determine beetle densities in each whole plot. In this experiment, the number of beetles caught in the four pitfall traps per whole plot were pooled. The data was log (count + 1) transformed and then analyzed as a randomized complete block design to determine whether there were significant whole plot effects. Again, arithmetic means are used in the figures.

Laboratory feeding studies. The carabids used in this study were field collected in August and September from the Michigan State University Muck Soils Research Farm, Clinton Co. and from a non-cultivated field at the Collins Road Entomology Research Farm, East Lansing. The onion maggots and eggs were again obtained from the lab of Dr. James Miller.

Three day study on predation of eggs. Eggs (100) were counted out onto a 2 cm square of wet filter paper in the center of a petri dish and one carabid beetle was placed into each dish. The dishes were then closed and placed in a growth chamber at 25°C with a photoperiod of 15:9 (L:D) d. The number of eggs eaten, eggs hatched and remaining 1st instars were recorded after 24 h. The filter paper and all remaining eggs and larvae were removed and replaced with 100 new eggs every 24 h for 3 d. The number of eggs each individual beetle consumed per 24 h was averaged over the 3 d assay and combined to calculate a mean S.E. per beetle.

One day study on predation of maggots. Third instars and a section of onion were placed on wet filter paper in petri dishes (seven/dish). One carabid beetle was placed into each dish. The dishes were then closed and placed in a growth chamber at 25°C with a photoperiod of 15:9 (L:D) d. The number of maggots eaten or attacked was recorded after 24 h and mean number eaten ± S.E. per species was calculated.

Foraging study. In 1998, a small study was done to determine the ability of carabids to find eggs on the soil surface versus below the surface. A similar study was done by Grafius and Warner (1989) with *Bembidion quadrimaculatum* L. For this study 100 ml soufflé cups (6 mcm dia. top, 4 cm diam. bottom, 3.5 cm high) were filled to a depth of 2 cm with sieved muck soil. Twenty eggs were placed either on the soil surface or 1 cm below the surface. To the cups one *B. quadrimaculatum*, one *P. lucublandus* or no carabids were added. After 24 h (20-23°C) the numbers of remaining eggs were recorded.

Results and Discussion

Field studies. In the spring experiment, the beetle densities were never significantly different between ambient, increased or decreaed predator plots. The global ANOVA for the spring experiment was not significant for carabids (May 29, F = 2.14, df =2,6, P = 0.19; June 19 (F = 1.96, df =2,6, P = 0.2177) (Figure 3) or for staphylinids (May 29, F = 3.38, df =2,6 , P = 0.0851, June 19, F = 1.74, df =2,6, P = 0.2597). When onion stands were counted at the global ANOVA was not significant for the numbers at third week (F = 1.12 , df = , P = 0.3984) or for numbers at harvest(F = 0.93, df = , P = 0.5647) (Figures 4 and 5). The populations were not trapped more often for fear that the trapping and the movement in and out of the plots would disturb the carabid populations. A control to measure egg survival in the field disintegrated and the data could not be collected.

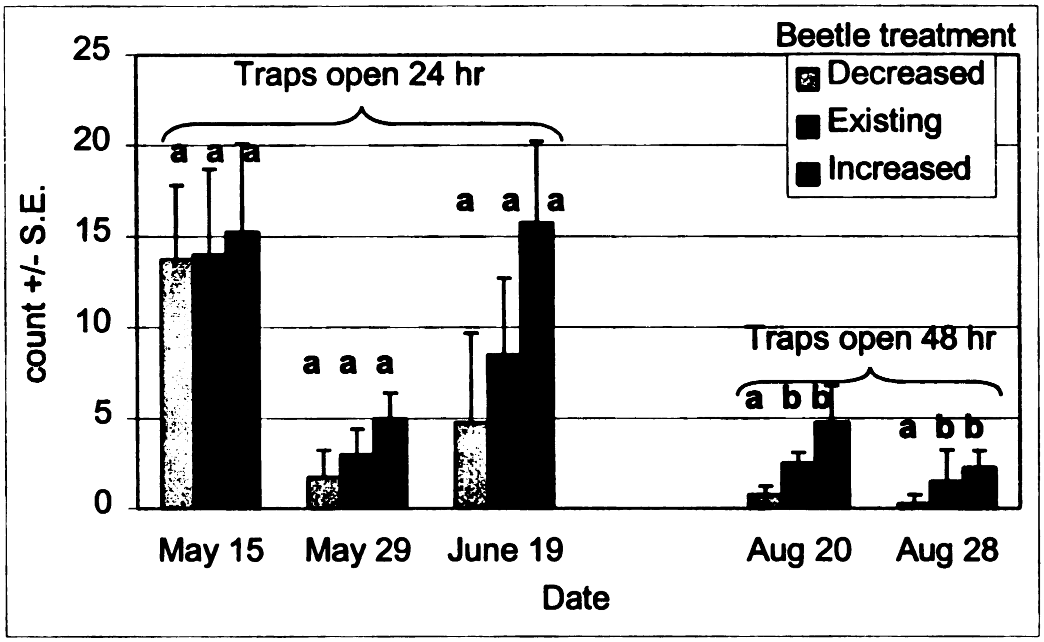


Figure 3. Number of carabids caught per attempted treatment +/- S.E. (decreased, existing and increased carabid densities) in an onion field during the growing season.
Different letters indicate significantly different means, *P*<0.05.

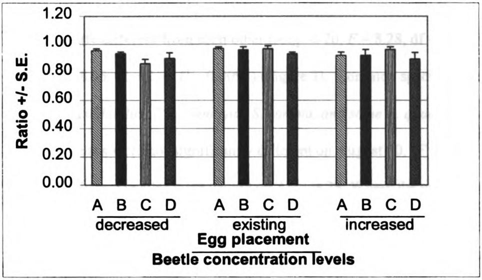


Figure 4. Ratio of the number onions **one month** after placing onion maggot eggs in the field to the number of onions the day the eggs were placed in the field +/- S.E. (A = 20 eggs on soil surface, B =10 eggs on soil surface and 10 eggs below soil surface, C = 20 eggs place in soil crack at onion base, D = no eggs) No comparisons were significantly different at $P<0.05$.

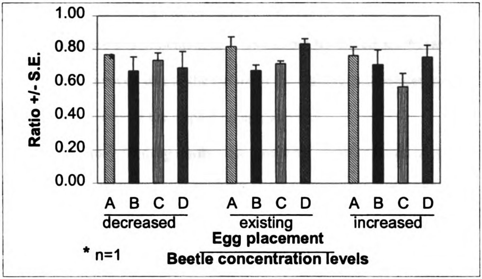


Figure 5. Ratio of the number onions **three months** after placing onion maggot eggs in the field to the number of onions the day the eggs were placed in the field +/- S.E. (A = 20 eggs on soil surface, B =10 eggs on soil surface and 10 eggs below soil surface, C = 20 eggs place in soil crack at onion base, D = no eggs). No comparisons were significantly different at $P<0.05$.

By the end of the growing season, the increased and decreased beetle density plots were significantly different from each other (August 20, $F = 8.28$, df = 2, 6, $P = 0.0031$, August 28, $F = 8.95$, df = 2, 6, $P = 0.0094$) (Figure 3). Common species were *P. chalcites, P. lucublandus, P. melanarius, S. comma, and some B. quadrimaculatum.* Staphylinids means were not significantly different on August 20, ($F = 0.59$, df = 2,6, $P = 0.7086$) and only two beetles were caught on August 28. Where the eggs were added there were no differences in the number of onion maggots or onion maggot pupae found ($t_{0.025} = 3.18$, df = 3, $P < 0.05$; $F = 1.08$, df = 2,6, $P = 0.4558$) (Figures 6 and 7). Where onion maggots were added, significantly more onion maggots were found in the decreased carabid treatment than in the increased treatment ($F = 5.63$, df = 2, 6, $P = 0.0289$) (Figure 8). Moreover, more maggots were found in the control cups where maggots were not accessible to the ground insects than were found in the treatment where the eggs were accessible ($t_{0.025} = 12$, df = 3, $P < 0.05$) (Figure 9).

From these experiments it appears carabid levels impact the number of maggots that survive. However, due to the nature of the experimental design it is not possible to make conclusions about the impact on egg survival.

Laboratory feeding study. As shown by others (Tolmin et al 1975, Drummond 1982, Grafius & Warner 1989), carabids will eat onion maggots and onion maggot eggs when offered to them under laboratory conditions (Table 1). The sample size in the foraging study was not large enough to make an assessment (Table 2).

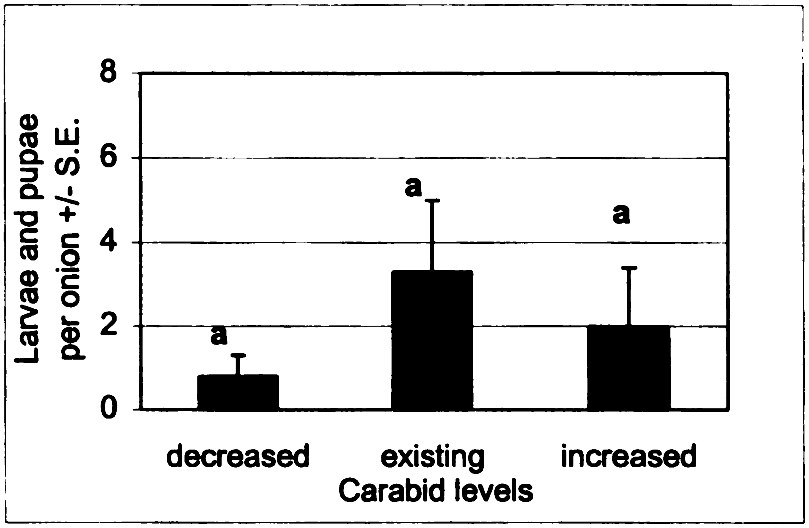


Figure 6. Number of onion maggots and pupae found in or beneath an onion the field 4 weeks after placing 20 onion maggot **eggs** on the onion, (+/- S.E.) within different carabid densities. Different letters indicate means significantly different, P<0.05.

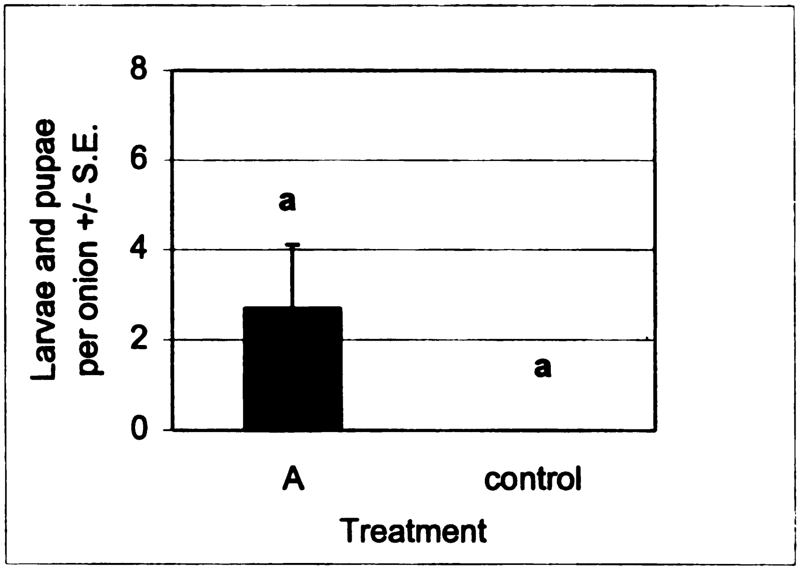


Figure 7. Number of onion maggots and pupae found in or beneath an onion in an onion field 4 weeks after placing 20 **onion maggot eggs** on the onion, +/- S.E.; A= accessible to ground dwelling predators. Control = not accessibile to ground dweeling predators. Different letter indicate means significantly different, P>0.05

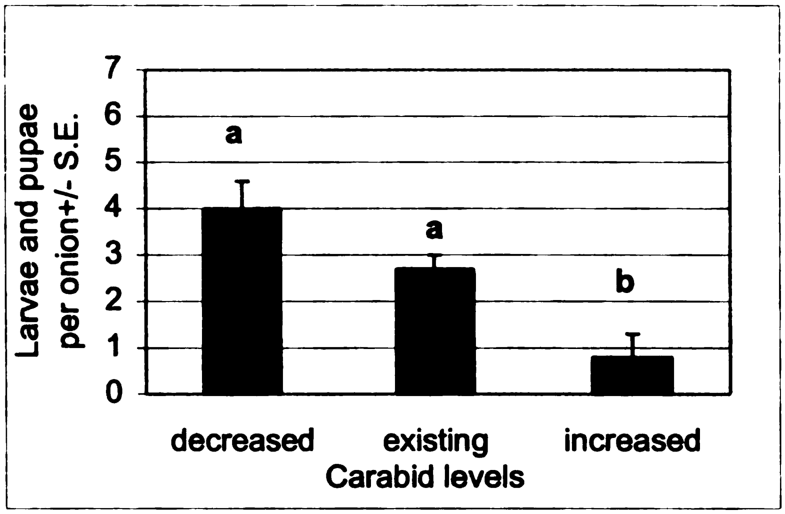


Figure 8. Number of onion maggots and pupae found in or beneath an onion in the field 4 weeks after placing 7 onion **maggots** on the onion (+/- sd) within different carabid densities. Different letters indicate means significantly different, $P<0.05$.

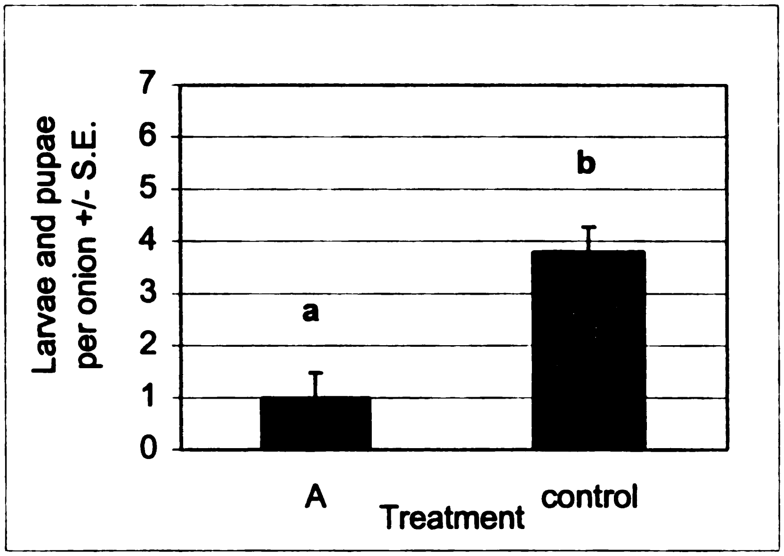


Figure 9. Number of onion maggots and pupae found in or beneath an onion in an onion field 4 weeks after placing 7 onion **maggots** on the onion, +/- S.E.; A= accessible to ground dwelling predators. Control = not accessbile to ground dwelling predators. Different letters indicate means significantly different, $P<0.05$.

Table 1. Mean number of *Delia antiqua* eggs and maggots eaten by carabids in a laboratory feeding study.

	3 Day Egg Study			1 Day Maggot Study		
Species	n	# offered per day	Mean # eaten per day ± S.E.	n	# offered	Mean # eaten ± S.E.
Poecilus chalcites	7	100	69 ± 11	9	7	5 ± 2
P. lucublandus	3	100	99 ± 1*	4	7	6 ± 1
Pterostichus melanarius	3	100	71 ± 13	8	7	7 ± 1
Anisodactylus sanctaecrucis	1	100	96	1	7	4
Stenolophus comma & lecontei	5	100	92 ± 3	11	3	2 ± 1
Harpalus spp.	3-6	100	84 ± 12	10	7	6 ± 1
Scarites spp.	4	70	10 ± 5*	-	-	-
Cicindela spp.	3	70	8 ± 4	4	6	5 ± 1

*2 d

Table 2. Mean number of eggs on the soil surface or below the soil surface eaten by *P. lucublandus* and *B. quadrimaculatum.*

	Number of eggs not found ± S.E.	
Species	eggs placed on surface	eggs placed 1 cm below surface
Poecilus lucublandus	10 ± 2 (5)	6 ± 4 (4)
Bembidion quadrimaculatum	12 ± 3 (4)	11 ± 5 (3)
Control (no carabids)	3 ± 3 (3)	3 ± 1 (3)

Conclusions

The first half of this experiment is inconclusive. When looking at the mean number of beetles caught per treatment (Figure 3) there appeared to be a trend of more carabids in the high beetle density plots. There may have been significantly different carabid densities in the plots but the trapping method may not have been effective. Traps should have been left open for a longer period of time or more often. In addition, a better control was needed to monitor the fate of the eggs placed in the field. Knowing the number of eggs that hatched was important to determine whether there was a difference between the sub-plot treatments.

The second half of the experiment indicates that at the end of the growing season carabids may reduce onion maggot numbers by half and thereby reducing the number of females ovipositing in the spring when the crop is most susceptible to damage.

Effect of Insecticide Treatment and Soil Organic Matter Content on Onion Growth and Damage by Onion Maggot, *Delia antiqua* Meigen (Diptera: Anthomyiidae)

ABSTRACT

Cyromazine and chlorpyrifos were tested on soils of differing organic matter content for control of onion maggot and for effects on onion germination and growth. Onions received one of three treatments: cyromazine in a seed coating, chlorpyrifos at planting, or no insecticide and were gown in soils differing in organic matter content or other composition. Onion maggot eggs were placed on half of the treatments and allowed to develop. The first greenhouse study showed that cyromazine and chlorpyrifos were equally effective at controlling onion maggot (99 and 85% plant stand after germination respectively), compared to the control (17% plant stand) on muck soil of 20, 40, and 60% organic matter content. The soil with 20% had a negative effect on onion growth, with decreased survival after germination and lower stands. The second greenhouse study also showed cyromazine and chlorpyrifos were equally effective in controlling onion maggot (89% and 92% plant stand respectively), compared to the control (39%) on a sandy loam, an organic sand, and a peat humus. Both insecticides performed better on the sandy loam (94%) than on either the organic sand (69%) or the peat humus (57%). However, the onion size was significantly smaller on the sandy loam. In the field, the insecticides were equally effective, however, the resulting yields were not the same; cyromazine had the greatest yield and the control the smallest. The efficacy of both insecticides was higher than the control on the organic sand (63% plant stand) than on the peat humus (43% plant

stand). These results indicate that cyromazine does not differ from chlorpyrifos in its efficacy at different soil organic matter contents. However, soil organic matter content does affect the growth of onions.

Introduction

Onions (Alliaceae: *Allium cepa*) are a major vegetable crop in the United States, second only to lettuce production by weight (Kortier-Davis et al. 1995). In 1996, Michigan growers planted 2511 ha of dry bulb onions with a production value of $15.5 million (MASS 1997). Most of these onions were directly seeded into histosols, commonly referred to as "muck" soils which have high organic matter content (Lucus 1982). Histosols typically have good water retention, high nitrogen content, and simple nutrient management and harvest practices (Zandstra et al. 1996). In Michigan, muck farming areas were created by draining lakes and swamps resulting in muck soils that vary in organic matter content within and between fields (Warncke, personal communication).

The onion maggot, *Delia antiqua* Meigen (Diptera: Anthomyiidae), is a serious onion pest. In Michigan, onion maggots over-winter in the soil as pupae and emerge as adult flies in May. The females lay their eggs at the base of onion seedlings. After hatching in 3-5 days, the larvae feed on the onion bulbs and roots for three instars (2 to 3 weeks). The larvae then pupate, and adults emerge in July. By this time, the onions have developed a skin over the bulbs that is more resistant to onion maggot attack, and the female flies prefer to lay their eggs on previously damaged onions (Finch & Eckenrode 1985, Hausmann & Miller 1989). The offspring of the July generation emerge in August and September and lay eggs on onions left behind in the field after the harvests in

August-October. The first generation larvae, therefore, have the greatest direct effect on the yield and quality of the onion crop. In severe years, onion maggot can reduce onion stand in commercially treated fields by 40-80% (Zandstra et al. 1996).

Historically, the common practice for onion maggot management on commercial farms was to apply granular insecticides in the seed furrow at planting and then follow with foliar sprays as often as once a week starting in June (Liu et al. 1982). The result of this intensive exposure is that the onion maggot is now resistant to cyclodiene, organophosphate, carbamate, and pyrethroid insecticides (Howitt 1958, Guyer & Wells 1959, Harris & Svec 1976, Harris et al. 1981, and Carroll et al. 1991). Foliar sprays used against adults are ineffective and may have contributed to resistance development (Finch et al. 1986). Application of granular insecticides in the seed furrow by itself is effective against the very damaging first generation of onion maggot (Ritcey et al. 1991). Chlorpyrifos (Lorsban, Dow Elanco), an organophosphate insecticide, and cyromazine (Trigard, Novartis), an insect growth inhibitor, are the only remaining effective chemicals registered for use against onion maggot.

Cyromazine (Trigard, Novartis) is an insect growth regulator that stiffens the larval cuticle via an undetermined mode of action and prevents molting (Kotze & Reynolds 1991). It will be registered for use against onion maggot for the 1999 growing season (Bishop, personal communication). In the early 1980's, cyromazine was found to be useful against species of flies such as leaf miners, *Liriomyza trifolii* (Burges) and cultivated mushroom pests, *Lycoriella auripila*, and it has been fed to cattle and fowl to kill flies in feces (Shen & Plapp 1990). Hayden and Grafius (1990) reported the potential of cryromazine as a management tool for onion maggot. Cyromazine was first used against onion maggot as a soil drench; it is now being incorporated into an onion seed treatment at the the low dosage of 50g of active ingredient kg of seed (Grafius 1984, Grafius & Boylan-Pett 1991).

Despite the success of cyromazine for onion maggot control, there have been some reports of failures. During the growing season of 1995, Grafius and Davis (1996) found cryromazine ineffective at one field site. They suggested that this might have been due to dry conditions, failure of pellet breakdown, or soil with low organic matter content. Sandy soils have been implicated in low onion stands in New York (Taylor, personal communication).

Cyromazine may have fewer negative impacts than conventional insecticides on natural enemies of the onion maggot (Miller et al. 1981, Samsoe-Petersen 1985, Wills et al. 1990) and, therefore, might lend itself well to a more integrated approach to control onion maggot. Determining the effectiveness of cyromazine is important in constructing reliable integrated pest management strategies. This study was designed to test cyromazine and chlorpyrifos effects on onion germination, plant development, and onion maggot control in soils of different organic matter content.

Methods

Greenhouse studies. Two studies were conducted in the Center for Integrated Plant Systems greenhouses at Michigan State University. Both were randomized complete block designs with a split-plot arrangement of treatments, insecticide treatments within soil type. In both greenhouse studies, each soil flat (51 x 25 cm) was physically divided lengthwise with double layer of PVC duct tape into 3 equal sub-plot sections, 8 cm wide. Twenty-five onion seeds were sown in 1 cm deep furrows that ran the length of each sub-plot. Treatments were randomly assigned: cyromazine coated on the seeds, granular chlorpyrifos in the furrow, or no insecticide.

Greenhouse Study 1. Whole plots consisted of a muck soil amended to create one of three different organic matter levels. The plots were arranged into 8 blocks. The muck soil, categorized as "Houghton muck," was from the Michigan State University Muck Soils Research Farm, Clinton Co. Michigan. The unamended soil had an organic matter content of 80%, which is higher than that of most commercial onion fields. The soil was mixed with pure silica sand to achieve three different organic matter contents: 20%, 40%, and 60% by weight. These levels were within the range of organic matter contents of muck soils farmed in Michigan. Each seedling flat contained 3 l of soil.

The onion seed ('Legacy,'Sun Seeds) used in this study came from a single seed lot. A portion of the lot was thinly coated with cyromazine (appox. 0.16 mg of active ingredient per seed) by Dr. Alan Taylor, Cornell University. The chlorpyrifos treatment received granular Lorsban 15G, at the label rate of 3.7 oz. per 1000 row foot. All seeds had been treated with the fungicide thiram (ProGro). Every other day during the experiment, each seedling flat received 0.5 to 1 l of water via a sprinkling can.

When the onions had reached the two leaf stage (42 days post planting), sub-sub plots were assigned: half receive onion maggot eggs, the other half did not. In the maggot egg treatments, two eggs were placed on the base of each onion. Eggs came from a culture maintained in the lab of Dr. James Miller, Department of Entomology, Michigan State University.

Greenhouse Study 2. Whole plots consisted of two muck soils and one mineral soil. The plots were arranged into 4 blocks. The muck soil used in this study came from a commercial farm in Newaygo Co Michigan where cyromazine had reportedly failed in a field trial. The two different muck soils were collected from locations 90 m apart within the same field. One muck soil was "peat humus" with 73% organic matter and a 6.2 pH; the other was "organic sand" with 20% organic matter and 5.9 pH. The inorganic soil came from the Michigan State University Potato Research Farm in Montcalm Co. Michigan. The soil was sandy loam (66% sand, 24% silt, 10% clay) with 2% organic matter and 7.2 pH. Each seedling flat contained 4.26 L of soil.

Novartis Crop Protection, Inc (Hillard, Ohio) supplied the seed for this study. A portion of the seed ('Quantum') was pelleted with a clay coat that contained cyromazine (50g/kg seed).

All onion plants received onion maggot eggs 53 d after planting. The eggs were applied as in the first study. Each seedling flat received 0.5 to 1.5 ℓ of water every 1-2d via a sprinkling can.

Field study. A field plot study was planted in the same location at the farm in Newaygo Co. where the muck soil of higher organic matter content had been acquired for the second greenhouse study. The study was an incomplete block design with a split plot arrangement of treatments. As in the studies above, soil was the whole plot and the same three insecticide treatments were the subplots. Each of the five blocks was 3.7 m long and consisted of two adjacent raised onion beds 0.45 m wide. In one bed of each block, the soil was removed to a depth of 10 cm. This soil was replaced with 90 ℓ organic sand from the sandy area of the field (described in second greenhouse study). The onion seeds were planted May 12, 1997, using the same as in the second greenhouse study) with 100 onion seeds per sub-plot sown 1 cm deep.

Data collection and analysis. The number of emerged onion plants were counted on eight dates during the first greenhouse study and on four dates during the second greenhouse study. Two ratios were calculated from these counts for each treatment: 1) maximum number of seeds germinated / number of seeds planted and 2) number of plants alive at the two leaf stage / maximum number of seeds germinated. Onion plant size was measured as total length of photosynthetic cotyledon or leaf above ground. Measurements were taken on six dates in the first study and on four dates in the second study. The relative efficacy of insecticide treatments was evaluated by the ratio of healthy plants at the end of the study (11 d after eggs were placed on the onion plants in the first study and 14 d after in the second study) to the number of plants present the day the eggs were placed on the plants.

In the field study, the onion stand was counted on seven dates before harvest. At harvest (August 21,1997) the onions were counted and weighed. The ratio of number of plants at harvest to maximum number of plants counted during the season was calculated.

Ratios were arcsin transformed and count data were log(count+1) transformed. Comparisons were made by general linear model procedure, ANOVA (SAS Institute 1994) at the 5% level. HSD comparisons were done on least square means.

Results and Discussion

Greenhouse study 1. Soil organic matter affected the number of onions that survived from germination to the two leaf stage ($F = 5.37$, df = 2,14, $P = 0.0185$); survivorship was lower in the sandier soil (Table 1). This may have resulted in a soil effect on onion stand at the two leaf stage ($F = 4.04$, df = 2,14, $P = 0.0412$) in which onion stands were lower on the sandier soil. There was no significant soil or insecticide treatment effect on the number of onions germinated nor on the size of the onions at the two leaf stage.

The differences between insecticide treatments ($F = 32.92$, df =2, 18, $P = 0.0001$), between the treatments with onion maggots added and with no onion maggots ($F = 75.05$, df = 1,27, $P = 0.0001$), and the interaction of these two factors ($F = 47.52$, df = 2,27, $P = 0.0001$) were significant. Soil organic matter content, though it affected onion growth, did not affect efficacy of either insecticide. In plots with no onion maggot added, the survival of onions was the same on the three soils and for the three insecticide treatments (Table 2). In plots with onion maggots added, the stands of onions with the cyromazine and chlorpyrifos treatments were not different, and both were higher than onions planted without insecticide. The level of onion maggot damage in the cyromazine and chlorpyrifos treatments was not different to the controls without onion maggot. The interaction between soil and insecticide treatment was not significant, therefore, cell comparisons were not done.

Table 1. Greenhouse study 1: Mean comparisons of onions grown on muck soil of 20%, 40%, and 60% organic matter content and with insecticide treatments cyromazine, chlorpyrifos, and no insecticide[1].

% organic matter in soil	Cyromazine	Chlorpyrifos	No insecticide	Mean
	Ratio number germination/ number seed planted			
20%	0.73	0.61	0.62	0.65
40%	0.77	0.67	0.69	0.71
60%	0.77	0.74	0.72	0.74
Mean	0.76	0.67	0.68	
	Onion survival (number of onions at two leaf stage/ maximum number germinated)			
20%	0.72	0.67	0.77	0.72 a
40%	0.89	0.72	0.82	0.81 b
60%	0.76	0.84	0.89	0.83 b
Mean	0.79	0.74	0.83	
	Number of onions to reach the two leaf stage			
20%	12.9	11.3	12.0	12.1a
40%	17.3	11.8	14.5	14.5 ab
60%	16.3	15.5	15.1	15.6 b
Mean	15.5	12.9	13.9	
	Total onion leaf length (cm)			
20%	91.8	90.3	93.3	91.8
40%	91.8	79.5	90.1	87.1
60%	99.0	85.6	96.5	93.7
Mean	94.2	85.1	93.3	

[1]Means followed by a different letter within a column (a, b, c) are significantly different at $p < 0.05$

Greenhouse study 2. Onions grown on sandy loam were smaller than those grown on either of the two muck soils; soil effect (F = 47.19, df = 2,6, P = 0.0002) (Table 3). Onions grown on sandy loam were observed to grow not as robustly as the onions grown on muck soils.

Cyromazine and chlorpyrifos had the same level of efficacy which was higher than that of no insecticide, ANOVA (F = 25.01, df = 2,16, P = 0.0001) (Table 3). The survival of onions was also affected by the soil organic matter content (F = 13.89, df = 2,6, P = 0.0056). Onions grown on sand had a higher survival than those did on either muck type. The plots with sand appeared to develop a silt layer over the soil surface and to be more compacted than the muck soils. The survival of the onion maggots in this study may have been lower and therefore maggot damage was less.

Field study. In the field study, both insecticide treatment (F = 16.25, df = 2,12, P = 0.0004) and soil type (F = 12.40, df = 1,4, P = 0.0244) effected onion survival (Table 4). Onion stands were higher on the organic sand than on the peat humus (Table 4). Cyromazine and chlorpyrifos had the same level of efficacy, higher than with no insecticide. There was no interaction between insecticide treatment and soil. The size of each onion was not affected by soil or insecticide treatment. However, the total yield per row was affected. Cyromazine yield was the highest, followed by the chlorpyrifos and with no insecticide yields being the lowest (F = 20.74, df = 2,12, P = 0.0001).

Table 2. Greenhouse study 1: Mean comparisons of onion maggot control (stand after onion maggots : stand before onion maggots) of insecticides cyromazine and chlorpyrifos in muck soils of 20%, 40% and 60% organic matter[1].

	With maggots				No maggots			
% organic matter in soil	Cyromazine	Chlorpyrifos	No insecticide	Mean	Cyromazine	Chlorpyrifos	No insecticide	Mean
20%	1.00	1.00	0.13	0.71 b	0.95	1.00	1.00	0.98 a
40%	1.00	0.90	0.13	0.68 b	0.98	1.00	1.00	0.99 a
60%	0.97	0.64	0.28	0.63 b	0.96	0.98	1.00	0.98 a
Mean	0.99 x	0.85 x	0.17 y		0.96 x	0.99 x	1.00 x	

[1]Means followed by the same letter are significantly different at $p<0 .05$

Table 3. Greenhouse study 2: Mean comparisons of onions grown on sand, organic sand, or peat humus with cyromazine, chlorpyrifos, or no insecticide treatment[1].

Soil	Cyromazine	Chlorpyrifos	No insecticide	Mean
	Ratio number germination/ number seed planted			
Sand	0.39	0.27	0.39	0.35
Organic sand	0.52	0.50	0.55	0.52
Peat humus	0.54	0.53	0.58	0.55
Mean	0.48	0.43	0.51	
	Onion survival (number at of onions at two leaf stage/ maximum number germinated)			
Sand	0.78	0.94	0.92	0.88
Organic sand	0.72	0.95	0.85	0.84
Peat humus	0.94	0.91	0.87	0.91
Mean	0.81	0.93	0.88	
	Number of onion to reach two leaf stage			
Sand	9.0	5.0	8.8	7.6
Organic sand	12.3	9.0	11.8	11.0
Peat humus	12.3	12.3	12.3	12.3
Mean	11.2	8.8	11.0	
	Total onion leaf length (cm)			
Sand	7.3	5.2	6.8	6.4 a
Organic sand	21.0	18.1	19.0	19.4 b
Peat humus	16.5	18.8	22.8	19.4 b
Mean	14.9	14.0	16.2	
	Efficacy (number of onions after onion maggots/ number of onions before onion maggots)			
Sand	0.98	1.00	0.83	0.94 a
Organic sand	0.95	0.92	0.20	0.69 b
Peat humus	0.73	0.83	0.15	0.57 b
Mean	0.89 x	0.92 x	0.39 y	

[1]Means followed by a different letter within column (a,b,c) or row (x,y,z) are significantly different at $p < 0.05$

Table 4. Field Study in Newago Co.: Mean comparisons of onions grown on organic sand or peat humus with cyromazine, chlorpyrifos, or no insecticide treatment[1].

Soil	Cyromazine	Chlorpyrifos	No insecticide	Mean
	Survival (number of onions at harvest/ maximum number germinated)			
Organic sand	0.74	0.69	0.46	0.63 a
Peat humus	0.66	0.42	0.22	0.43 b
Mean	0.70	0.56	0.34	
	Onion yield (kg)			
Organic sand	4.8	3.8	3.2	3.9
Peat humus	5.3	2.7	1.5	3.2
Mean	5.1 x	3.3 y	2.4 z	
	Onion size (kg)			
Organic sand	0.074	0.072	0.073	0.073
Peat humus	0.090	0.063	0.076	0.076
Mean	0.082	0.068	0.075	

[1]Means followed by a different letter within a column (a, b, c) or row (x, y, z) are significantly different at $p < 0.05$

Conclusions

The results of these studies indicate cyromazine does not differ from chlorpyrifos in its control of onion maggot in muck soils that range in organic matter content from 20% to70%. The comparison of soils from the farm where cyromazine had failed, indicated thatthe organic content was probably not the causal factor for the failure. Soil type has an effect on the survival or size of an onion independent of the insecticide used.

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APPENDICES

APPENDIX A

Field Diagrams for Chapter 1.

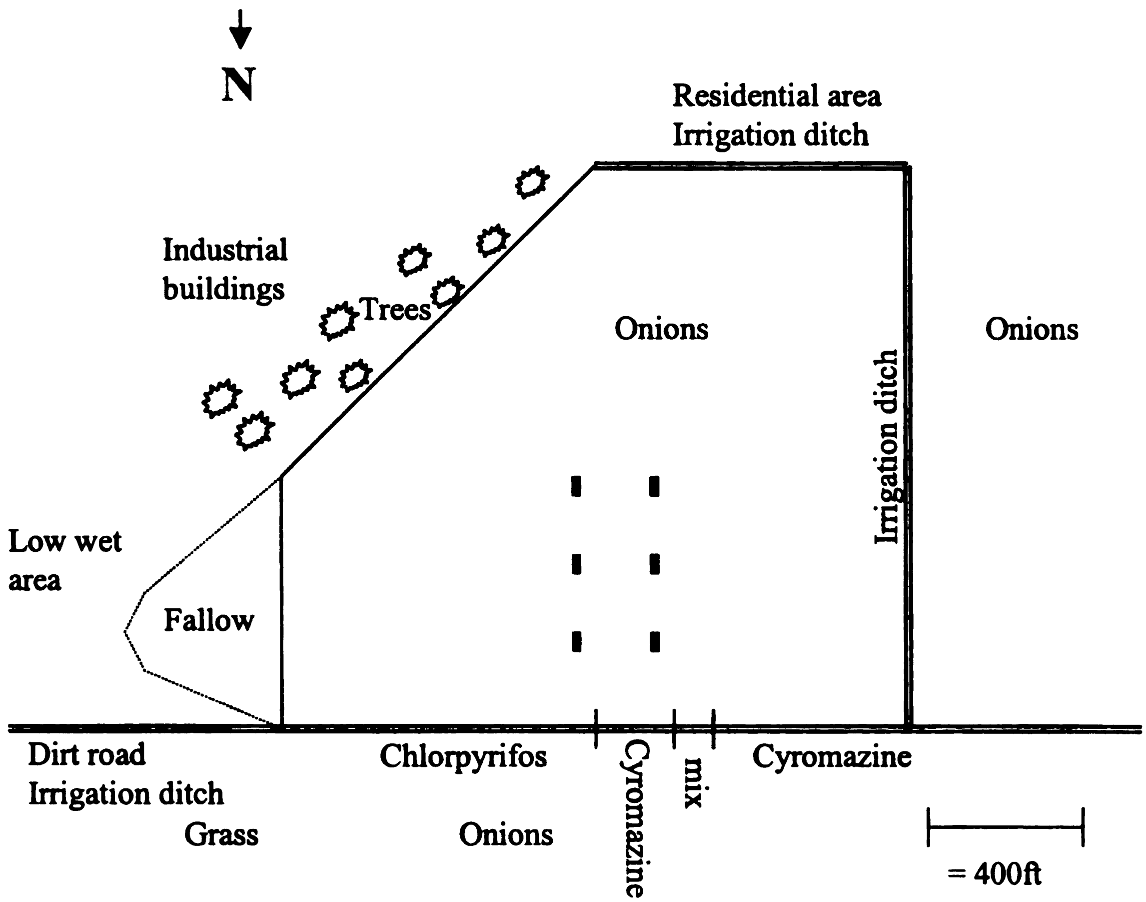

Figure 1. Ottawa 1 Site 1997

= Diagonal line of
3 pitfall traps

Newaygo Site 1997

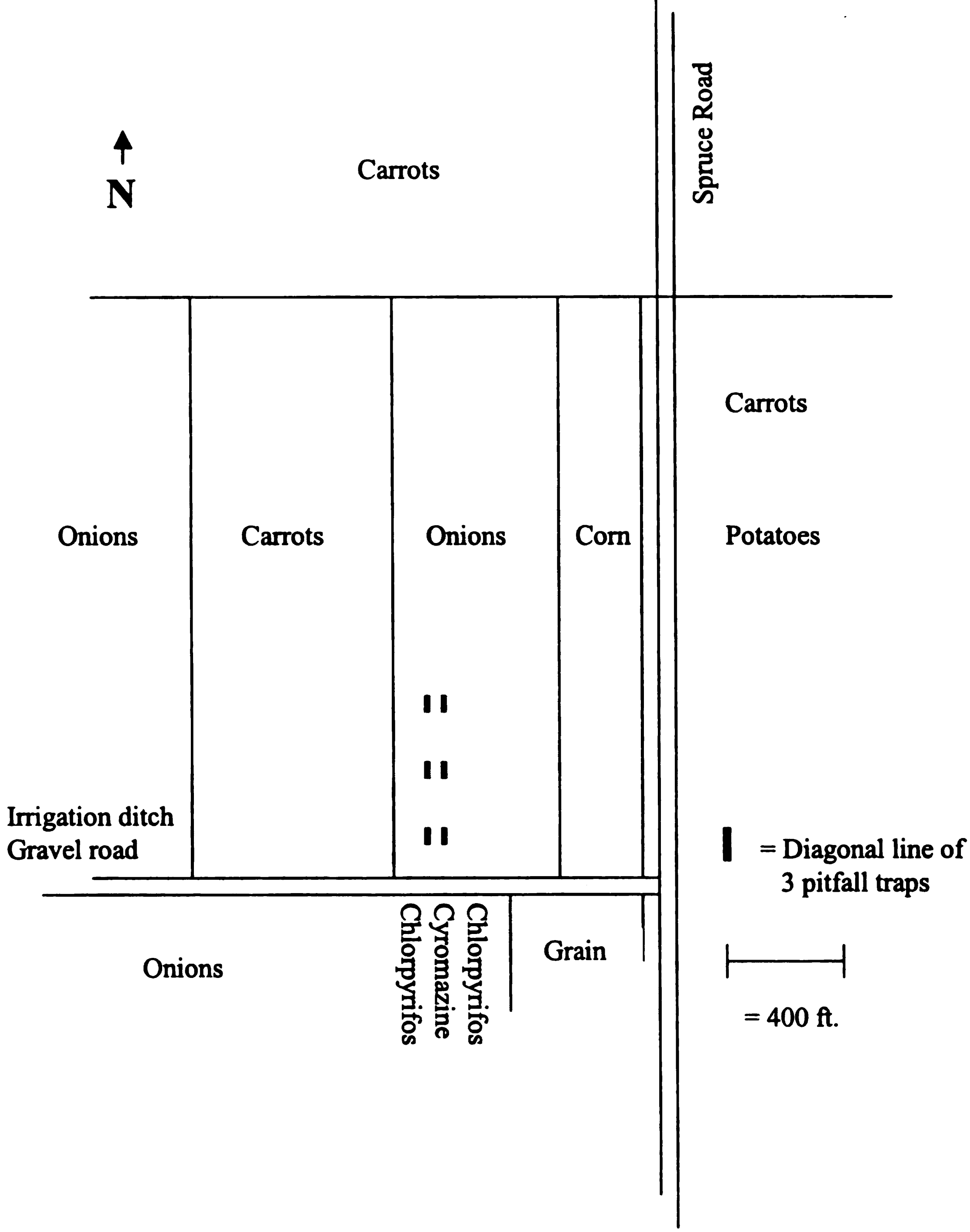

Figure 2. Newago site 1997

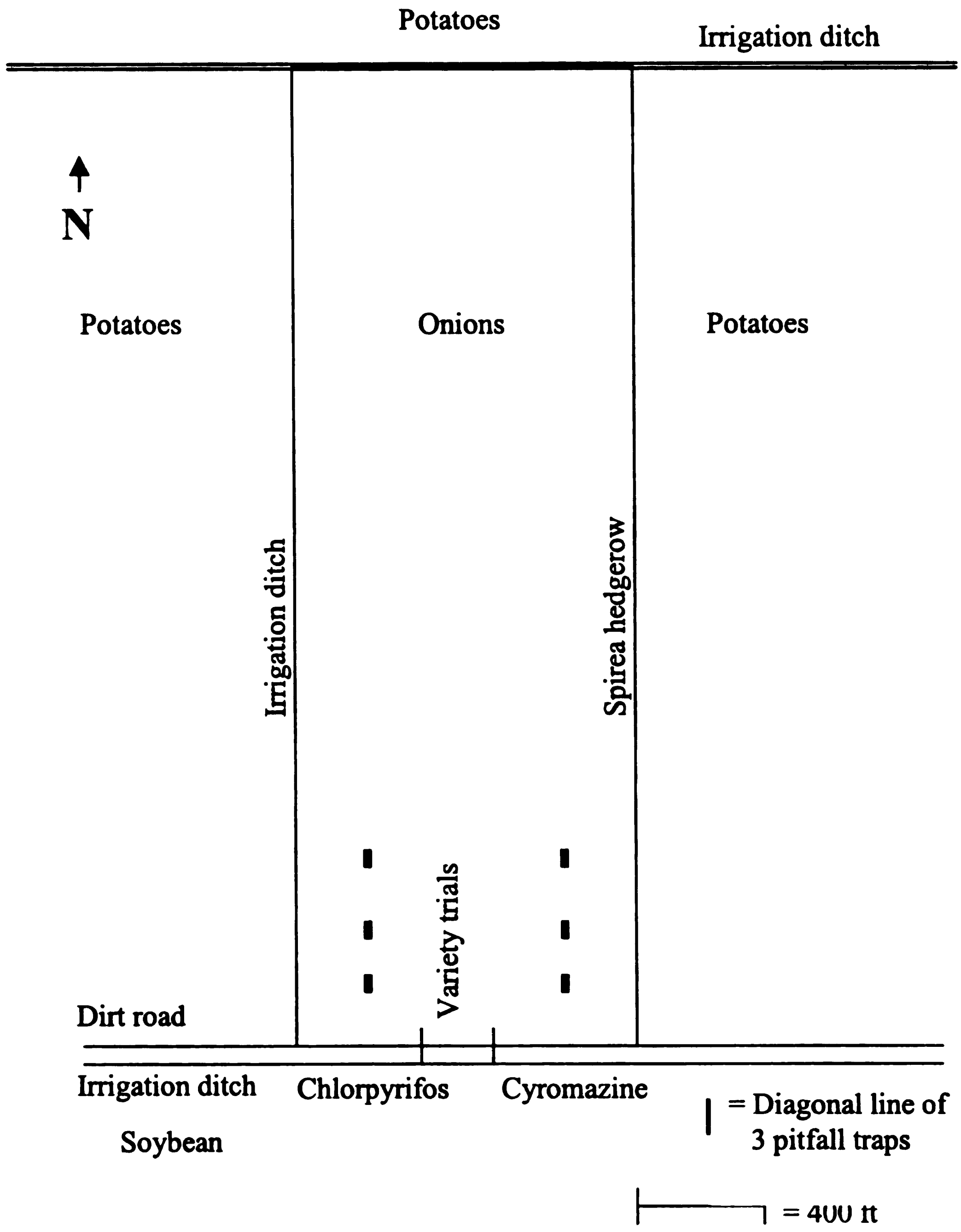

Figure 3 . Ingham County site 1997.

APPENDIX B

Record of Deposition of Voucher Specimens

APPENDIX 1

Record of Deposition of Voucher Specimens*

The specimens listed on the following sheet(s) have been deposited in the named museum(s) as samples of those species or other taxa which were used in this research. Voucher recognition labels bearing the Voucher No. have been attached or included in fluid-preserved specimens.

Voucher No: 12-98

Title of thesis or dissertation (other research projects):

INSECT GROWTH REGULATOR, CYROMAZINE, CONTROL OF ONION MAGGOT (*DELIA ANTIQUA* (MEIGEN)) AND EFFECTS ON POSSIBLE BIOLOGICAL CONTROLS

Museum(s) where deposited and abbreviations for table following sheets:

Entomology Museum, Michigan State University (MSU)

Other Museums:

Investigator's Name (s) (typed)

Sheila Ebert
Date

*Reference : Yoshimoto, C.M. 1978. Voucher Speciemens for Entomology in North America. Bull. Entomol. Soc. Amer. 24:141-42.

Deposit as follows:

Original: Include as Appendix 1 in ribbon copy of thesis or dissertation.
Copies: Included as Appendix 1 in copies of thesis or dissertation.
Museum(s) files.
Research project files.

This form is available from and the Voucher No. is assigned by the Curator, Michigan State University Entomology Museum.