DISSERTATION

PEST MANAGEMENT TACTICS
FOR THE WESTERN CABBAGE FLEA BEETLE
(*Phyllotreta pusilla* Horn)
ON BRASSICA CROPS

Submitted by

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In partial fulfillment of the requirements

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WE HEREBY RECOMMEND THAT THE DISSERTATION PREPARED UNDER OUR SUPERVISION BY MOHAMMED AL-DOGHAIRI ENTITLED PEST MANAGEMENT TACTICS FOR THE WESTERN CABBAGE FLEA BEETLE (*Phyllotreta pusilla* Horn) ON BRASSICA CROPS BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR DEGREE OF DOCTOR OF PHILOSOPHY

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ABSTRACT OF DISSERTATION

PEST MANAGEMENT TACTICS FOR THE WESTERN CABBAGE FLEA BEETLE (*Phyllotreta pusilla* Horn) ON BRASSICA CROPS

The western cabbage flea beetle, *Phyllotreta pusilla* Horn (Chrysomelidae: Coleoptera), is often the most important insect pest of brassica crops in the Rocky Mountain region. Flea beetle feeding results in chewed pits on the leaves and cotyledons that, when severe, can cause seedling mortality. Less severe feeding can cause delayed plant development and reduce height, yield, and produce quality. Insecticides have long been the most widely utilized control method for flea beetles. In this study, alternative management tactics such as cultural (planting density, interplanting and host plant resistance), mechanical (trapping), and chemical (repellents and insecticides) controls were investigated. In these studies action thresholds were also developed.

The western cabbage flea beetle showed feeding preferences within the Brassicaceae. Chinese cabbage, the cabbage cultivars 'Golden Acre' and 'Copenhagen Market' and the broccoli cultivar 'Green Goliath', were significantly most preferred. Cauliflower, Brussels sprout, collard, kale and the cabbage cultivars 'Red Acre', 'Earliana' and 'Salad Delight' and broccoli cultivars 'Love Me Tender Hybrid' and 'Premium Crop' were significantly least preferred by flea beetles.

Within an area, increasing plant density resulted in a significant decrease in flea beetle population infesting individual broccoli plants, but an increase in total number of flea beetles. A 40-cm in-row spacing plant density resulted in a significant decrease in flea beetle numbers in given area, but an increase in numbers infesting individual plants within that area. Interplanting of a more preferred host plant (radish) among a brassica crop can be

an effective mechanism to reduce western cabbage flea beetle infestation and subsequent damage. Flea beetle density was highest in plots with no radishes interplanted between broccoli plants. Interplanting radish within broccoli plants did not significantly affect head weight and subsequent yield compared with a sole crop of broccoli.

Flea beetles responded significantly to several visual and chemical stimuli. The colors Saturn green, Saturn yellow and white were significantly the most attractive to flea beetles compared to the transparent control. Allyl isothiocyanate baited traps were significantly attractive to western cabbage flea beetle adults. Traps baited with canola oil were significantly less attractive compared to allyl isothiocyanate. Increase in allyl isothiocyanate concentration up to 2% significantly increased the attractiveness of the traps.

Some of the insecticides and repellents tested in the field showed efficacy in controlling the adults of western cabbage flea beetle. Thiodan (endosulfan) and Asana (esfenvalerate) were significantly the most effective insecticides. The adult stage of western cabbage flea beetle may be best controlled by the application of Asana for rapid action or by Thiodan for prolonged effect up to two weeks. Margosan-O, SunSpray, Azatin, and diatomaceous earth were significantly the most effective tested repellents. Such repellents may be effective alternatives to conventional synthetic insecticides for the control of western cabbage flea beetle.

Western cabbage flea beetle feeding damage affected cabbage and broccoli plants, causing differences in size and weight of growing heads. Head diameter was significantly larger in plots maintained at 0-beetles per plant threshold compared to head diameter from plots maintained at 10-beetles per plant threshold and the control. Yield obtained from plots maintained at 0, 2 and 5-beetles per plant thresholds in 1997 and 0-beetles per plant threshold in 1998 was significantly higher compared to the 10-beetles per plant threshold and the control. Greatest head size reduction and yield loss occurred at the 10-beetles per plant threshold, suggesting an action threshold below that of 10-beetles per plant. The five flea beetles per plant threshold appears to be an appropriate action threshold for flea beetle control on seedling brassica crops.

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DEDICATION

In loving memory of my grandfather, Nassir, my grandmother, Meznah, my uncle, Mosa, and my nephew, Adeeb, who passed away during my stay here in the United States

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CHAPTER I

GENERAL INTRODUCTION

Flea beetles, subfamily Alticinae (Chrysomelidae: Coleoptera) (derived from the Greek 'haltikos' meaning "good at jumping") are minute to medium-sized compact beetles whose enlarged hind femora and jumping habit have earned them the name flea beetles. Flea beetles, *Phyllotreta* species in particular, are occasional pests of natural and cultivated brassica crops in North America (Bonnemaison 1965, Chittenden 1927, Pimentel 1961a, 1961b, Root and Tahvanainen 1969). The beetles most often inflict substantial damage on early-planted crops.

The three most common flea beetles attacking brassica crops in North America include the crucifer flea beetle, *Phyllotreta cruciferae* (Goeze), the striped flea beetle, *P. striolata* (Fabricius) (Metcalf and Metcalf 1993, Jones and Jones 1964), and the western cabbage (black) flea beetle, *P. pusilla* Horn (Chittenden and Marsh 1920). In addition, a number of other species of flea beetles belonging to different genera attack a variety of important vegetable crops, including: the palestriped flea beetle, *Systena blanda* Melsheimer; the potato flea beetle, *Epitrix cucumeris* (Harris); the western potato flea beetle, *E. subcrinita* LeConte; the tobacco flea beetle, *E. hirtipennis* (Melsheimer); the tuber flea beetle, *E. tuberis* Gentner; the eggplant flea beetle, *E. fuscula* Crotch (Cranshaw 1998); the yellow-black flea beetle, *Disonycha xanthomelas* (Dalman); the larger striped flea beetle, *D. crenicollis* Say; the three-spotted flea beetle, *D. triangularis* Say (Forbes 1900); the corn flea beetle, *Chaetocnema pulicaria* Melsheimer; and the sweetpotato flea beetle, *C. confinis* Crotch (Metcalf and Metcalf 1993).

Since the western cabbage flea beetle is abundant and highly mobile, crop rotations are ineffective. However, other cultural practices may show more promise. It is the primary goal of this research to determine if practices such as planting density, interplanting and host plant resistance can assist in management of western cabbage flea beetle. Furthermore, as part of an overall pest management system, the use of other practices (trapping, repellents and insecticide applications, and chemical management using action thresholds) were investigated.

PEST STATUS OF THE WESTERN CABBAGE FLEA BEETLE

The western cabbage (black) flea beetle, *Phyllotreta pusilla*, is a serious pest of brassica plant species. It primarily attacks garden crops and can become a pest in large commercial plantings. The species, very common throughout Colorado, was first reported as being particularly injurious to turnips and cabbage (Cooley 1906). In eastern Colorado it has proved potentially limiting to production of several crops, including seeded brassica vegetables, midsummer mustard, and canola. It is particularly damaging to producers of Certified Organic produce for whom management options are limited.

The western cabbage flea beetle ranges from the Dakotas, into Texas and Mexico, westward to Arizona, southern California and Nevada (Horn 1889, Chittenden 1903, Chittenden and Marsh 1920). *Phyllotreta pusilla* is also widely distributed in the Rocky Mountain region of Colorado and New Mexico. It is known to occur in isolated areas in Arizona, Wyoming, Nebraska, Oklahoma, and Kansas (Chittenden and Marsh 1920). In addition, *P. pusilla* may have a wider distribution than reported above.

Although the western cabbage flea beetle is primarily a pest of plants of the Brassicaceae family, it also occasionally attacks sugarbeets and other nonbrassica vegetable crops. Historically, turnip, mustard, and radish are generally the most favored food plants. Horseradish, rape, cabbage, cauliflower, water cress, Chinese mustard, nasturtium, bee-plant, sweet alyssum, candytuft, wild peppergrass, hedge mustard, wild water cress, and tansy mustard are other common hosts (Chittenden and Marsh 1920).

As with most other flea beetles, damage is primarily produced by the adult stage. Although the larvae feed on the roots of brassica plants, they cause little appreciable damage. Chief damage is done by the overwintered adult beetles as they move into newly planted areas and by the subsequent early summer generation. Beetles of the first generation are the most destructive to plants, particularly during June and July. Beetles appear suddenly in huge numbers, and large areas can be devastated before the grower becomes aware of their presence (Chittenden and Marsh 1920).

Adult western cabbage flea beetles feed on the foliage of plants. Because of their small size and active habits, flea beetles eat little at each feeding site, producing damage consisting of small round holes often described as "shot holes". Such damage often does little harm to the plant or yield, unless the plant is very small or flea beetles very numerous. However, older leafy vegetables may be damaged by cosmetic injuries to leaves, and very susceptible plants may be defoliated (Chittenden and Marsh 1920).

DESCRIPTION AND LIFE HISTORY

The adult western cabbage flea beetle is elongate oval, metallic copper in color, and approximately 1.5-2.0 mm long. Winter is spent as adults in protected places, such as under clods of earth, dead leaves, or other debris. They emerge in the spring and feed on wild vegetation, including tansy mustard, *Descurainia* (=*Sophia*) *pinnata* (Walter) and horseradish, *Radicula armoracia* L., until spring seeded plants are available (Chittenden and Marsh 1920).

Females lay light yellow oval-form eggs approximately 0.5 mm in length. Eggs are deposited in cracks in the soil about the roots of the host plant. The larvae of flea beetles are thread-like in appearance, uniformly white, except for the head sclerites, the legs, and a chitinized area on the caudal subabdominal segment, which are pale chestnut brown. The mature larva is approximately 5 mm in length and from 0.5 to 0.65 mm in width. The larvae spend their lives feeding on the roots of brassica plants. Pupation occurs in the soil in the vicinity of the roots on which larvae fed. The pupa is approximately the same size as the adult and is entirely white (Chittenden and Marsh 1920).

There are typically three generations of beetles produced per year. The complete life cycle from egg to adult varies among generations. The total duration for the first generation takes about 50 days. Chittenden and Marsh (1920) observed egg laying to start 14 April, eggs hatching 24 April, larvae pupating on 23 May, with first adults emerging on 3 June. In the second generation total duration was reported to take about 29 days with eggs deposited on 26 June and hatching 1 July. Larvae pupated on 19 July and second generation adults first emerged on 25 July. The duration of the third generation is about 39 days. Deposition of eggs started on 12 August hatched on 19 August, and larvae pupated on 10 September. First adults were noticed to emerge on 20 September.

FLEA BEETLE MANAGEMENT

Western cabbage flea beetle management is usually directed at the adult stage early in the spring when plants are small and most susceptible to defoliation. Larval feeding damage to plant roots is minor and control is not generally productive. Later generations of adult flea beetles can cause some feeding damage, but brassica plants are better able to compensate for this injury at this stage through increased summer growth. Leafy brassicas, however, may sustain serious cosmetic injuries.

Although insecticides are considered the first line of defense, especially during outbreaks, some alternative control methods have been given attention. These include the use of cultural practices, feeding deterrents and insect repellents, insect-resistant varieties, and the use of biorational insecticides.

During the last few decades, integrated control has been attempted to minimize the increasing problems with the use of insecticides. Although the approach does not eliminate the use of insecticides as a control method, it modifies their use with the integration of other control methods. The National Academy of Sciences (1969) has defined integrated control as "a concept of pest control in which all control techniques are evaluated and consolidated into a uniform program to manage pest populations so that economic injury is prevented and any detrimental effects to the environment are minimized".

It is the primary goal of this research to determine a control strategy which blends several control options consistent with the integrated control philosophy. This can be achieved through the use of cultural practices such as manipulation of plant density, interplanting, and host plant resistance as well as the use of other control options such as mass trapping. The application of insecticides, repellents and deterrents was also included as a mean to manage flea beetle. Chemical management using action thresholds was also included as a part of this project.

Cultural Control

A cultural control method that has been used against *P. pusilla* is clean cultivation. This approach eliminates the brassica weed species (e.g., mustards) that serve as alternative food for the beetles and as breeding sites for their larvae (Chittenden 1903). Also, when planting brassica crops, planting to a well-prepared seedbed can promote rapid seedling growth and help overcome insect injury (Cranshaw 1998). In the fall and after harvest, plowing weed and crop debris can limit overwintering sites for the adult flea beetles and, thus, allows fewer numbers of them to survive through the winter. However, flea beetles are very active and mobile and can migrate from one field to another; making it difficult for these cultural controls to effectively reduce their attack.

Chittenden and Marsh (1920) suggested as an alternative to chemical control the use of an early-season trap crop, where a very small planting (e.g., one percent of anticipated acreage) of preferred brassica crop (e.g., radish, mustard, or turnip) is planted.

Trap crops are usually planted along a field edge with adult flea beetles attracted to the tallest, earliest crops available. Once beetles are actively feeding in these trap crops they can be swept or sprayed with an effective foliar insecticide minimizing the development of economically damaging infestations in the primary brassica crop.

Changes in plant density and intercropping or interplanting can be effective approaches in the cultural control of western cabbage flea beetle infesting brassica crops. Increasing plant density may reduce plant infestation, perhaps due to changes in the microenvironment or in the attractiveness of the crop to a particular pest (Coaker 1987). Dense plantings lower the contrast of plants against the soil that is used by flying insects to find their host plant.

Intercropping or interplanting a brassica crop with a susceptible, tolerant, more favorable host plant, which can be used as a trap crop, also may effectively divert flea beetle attack from the main crop (Hokkanen 1991). The more attractive and preferred host plant is utilized as a diversionary crop that can be sacrificed after establishment of the main crop. Interplanting collards with wild mustard resulted in reduced density of flea beetles, *P. cruciferae* (Altieri and Gliessman 1983). Flea beetle density was reduced on weedy collards compared to those weed-free because the beetles preferred wild mustards to collards.

The employment of resistant cultivars in the cultural control strategy for the long-term management of flea beetles is also important. Flea beetles can discriminate among different oilseed rape cultivars, suggesting some kind of resistance in these cultivars that might be useful for controlling flea beetle damage in oilseed rape. Anderson et al. (1992)

studied the feeding preference of the flea beetle, *P. cruciferae*, for two oilseed rapes, *Brassica napus* (cv. 'Westar') and *B. campestris* L. (cv. 'Tobin'); white mustard, *Sinapis alba* L. (cv. 'Tilney'); and crambe, *Crambe abyssinica* Hochs (cv. 'Meyer'). Flea beetle feeding was significantly higher on oilseed rape than on crambe, and feeding damage was less on white mustard than on oilseed rape. They noticed that crambe did not inhibit flea beetle presence and feeding, and feeding pits were often shallow and smaller. They suggested that crambe tissues might have a gustatory deterrent that inhibits further feeding. Their results demonstrated flea beetle resistance in crambe, and confirmed the reports of Putnam (1977) and Lamb (1984) regarding resistance in white mustard.

Biological Control

Although the western cabbage flea beetle is largely free from natural enemies, several species of birds and three species of internal parasites have been reported to attack the beetle. *Perilitus epitricis* Viereck is a braconid wasp parasite of the adult flea beetle. Chittenden and Marsh (1920) observed that *P. epitricis* parasitized 16% of western cabbage flea beetles and were noted to have an even greater influence on the related striped cabbage flea beetle, *Phyllotreta vittata* Fab. Other parasites that attack the adult beetles are nematodes and gregarine worms. The species of birds reported to feed on *P. pusilla* are the common and Texas nighthawks, *Chordeiles virginianus* Gmelin and *C. acutipennis* Hermann, white-throated swift, *Aeronautes saxatalis* (=*A. melanoleucus*) (Woodhouse), horned lark, *Otocorys alpestris* L., starling, *Sturnus vulgaris* L., song sparrow, *Melospiza melodia* Wilson, chipping sparrow, *Spizella passerina* Bechstein, tree swallow, *Iridoprocne* (=*Tachyncincta*) *bicolor* (Vicillot), and marsh wren, *Cistothorus* (=*Telmatodytes*) *palustris* (Wilson) (Chittenden and Marsh 1920).

Chemical Control

Most flea beetle treatments are foliar sprays to protect against feeding of the adult beetle, particularly in early spring. In early experiments it was noted by Chittenden and Marsh (1920) that foliar applications did not kill the beetles but drove them away from the treated areas as the insects seemed to avoid treated plants and feed on untreated ones or untreated parts of a plant. It was noted that repellents and deterrents (e.g., tobacco dust and arsenicals) worked more effectively against this insect (Chittenden 1903, Chittenden and Marsh 1920). Application of a strong solution of soapsuds killed the beetle instantly, and sprinkling a mixture of wetted fresh cow manure on the plant drove the beetle away (Howard 1898). As adult flea beetles have the ability to migrate or be carried by wind from one field to the other, long term control with repeated applications may be required.

Mechanical Traps

Traps, in general, can be either attractive, relying on physical or chemical stimulus to lure insects into them, or passive, collecting insect incidentally. Traps with chemical stimulus (i.e., semiochemicals) may be used in Integrated Pest Management (IPM) programs in surveys to monitor for the arrival and/or suppression of a certain pest species. Traps can be also used as a method for monitoring adult flea beetle populations in the field and to determine whether an insecticide application to fields of brassica crop plantings is warranted.

The use of sticky traps can be effective in controlling the active flea beetles especially when they occur in great numbers. The "Wisley turnip-fly trap" has been tested against two flea beetle species, *Phyllotreta consobrina* Curtis and *P. undulata* Kutsch. on turnip. The trap gave good results in capturing adult flea beetles (Lefroy 1914).

Chemical stimuli can be used as baits to attract insects to traps. Boll weevil traps baited with allyl isothiocyanate were used in a study by Burgess (1984) to monitor for the abundance of *P. striolata* and *P. cruciferae* in parkland rapeseed and canola crops in Western Canada. Color traps baited with allyl isothiocyanate, a powerful attractant to flea beetles, may elicit a different response than when the color traps without the bait. Sometimes, the type or color of the traps used with the attractant does not restrain flea beetles from being strongly attracted to the traps. It was reported that the flea beetle, *P. striolata*, is strongly attracted to traps baited with allyl isothiocynate regardless of the type and color of the traps (Lamb 1983).

RESEARCH OBJECTIVES

The purpose of this project was to evaluate different management tactics for the western cabbage flea beetle, *P. pusilla*. Therefore, studies were conducted to meet the following program objectives:

1) **Objectives related to host plant preference of the western cabbage flea beetle:**
   a) To evaluate various brassica crop species and cultivars for relative susceptibility and preference of the western cabbage flea beetle.
2) **Objectives related to the effect of host plant density and interplanting on the population density of the western cabbage flea beetle:**
   a) To investigate how differences in host plant density affect flea beetle populations;
   b) To determine if interplanting with a flea beetle-susceptible, tolerant host would reduce infestation of the seedling main crop.
3) **Objectives related to attractiveness of color traps and allyl isothiocyanate to western cabbage flea beetle adults:**
   a) To evaluate colors for attractiveness to the beetles;
   b) To evaluate allyl isothiocyanates and related compounds for attractiveness.
4) **Objectives related to evaluation of various insecticides and repellents for western cabbage flea beetle control:**
   a) To evaluate the effectiveness of various insecticides and repellents for western cabbage flea beetle control under field conditions.

5) Objectives related to development of action threshold:

a) To determine if an economic threshold could be delineated that would allow management decisions to be made well before feeding damage by the western cabbage flea beetle reached the economic injury level;

b) To establish action thresholds for western cabbage flea beetle on different host plants.

REFERENCES CITED

Altieri, M. A., and S. R. Gliessman. 1983. Effects of plant diversity on the density herbivory of the flea beetle, *Phyllotreta cruciferae* Goeze, in California collard (*Brassica oleracea*) cropping systems. Crop Protection. 2: 497-501.

Anderson, M. D., C. Peng, and M. J. Weiss. 1992. Crambe, *Crambe abyssinica* Hochst., as a flea beetle resistant crop (Coleoptera: Chrysomelidae). J. Econ. Entomol. 85: 594-600.

Bonnemaison, L. 1965. Insects pests of crucifers and their control. Ann. Rev. Entomol. 10: 233-256.

Burgess, L. 1984. Changes in relative abundance of the flea beetles *Phyllotreta striolata* and *Phyllotreta cruciferae* (Coleoptera: Chrysomelidae) in Saskatchewan parkland with increasing distance from the boreal forest. Can. Entomol. 116: 653-656.

Chittenden, F. H. 1903. A brief account of the principal insect enemies of the sugar beet. U. S. Dept. Agr. Div. Entomol. Bull. 43: 18-19.

Chittenden, F. H. 1927. The species of *Phyllotreta* north of Mexico. Entomol. Am. 8: 46-47.

Chittenden, F. H. and H. O. Marsh. 1920. The western cabbage flea beetle. USDA, Bulletin No. 902. 21 pp. Washington D.C.

Coaker, T. H. 1987. Cultural methods: the crop. Pp.69-88. *In* A. J. Burn, T. H. Coaker and P. C. Jepson (eds.), Integrated Pest Management. Academic Press, London, UK.

Cooley, R. A. 1906. Biological departments. Annual Report, Montana Agricultural College 255-272.

Cranshaw, W. 1998. Pests of the West: Prevention and Control for Today's Garden and Small Farm. Fulcrum Publishing, Golden, Colorado, 248 pp.

Forbes, S. A and C. A. Hart. 1900. The economic entomology of the sugar beet. Univ. Ill. Agr. Exp. Sta. Bull. 60: 397-532.

Hokkanen, H. M. 1991. Trap cropping in pest management. Ann. Rev. Entomol. 36: 119-138.

Horn, G. H. 1889. A synopsis of the Halticini of boreal America. Trans. Am. Entomol. Soc. 16: 163-320.

Howard, L. O. 1898. Injury by the western flea-beetle, *Phyllotreta pusilla* Horn. U. S. Dept. Agr. Div. Entomol. Bul. 10: 92-93.

Jones, F. J. W and M. G. Jones. 1964. Pests of Field Crops. Edward Arnold Ltd. London. 406 pp.

Lefroy, H. M. 1914. Contributions from the Wisley laboratory. XXIII. A trap for turnip fly. J. Roy. Hort. Soc. Engl. 40: 269-271.

Lamb, R. J. 1983. Phenology of flea beetle (Coleoptera: Chrysomelidae) flight in relation to their invasion of canola fields in Manitoba. Can. Ent. 115: 1493-1502.

Lamb, R. J. 1984. Effects of flea beetles, *Phyllotreta* spp. (Chrysomelidae: Coleoptera, on the survival, growth, seed yield, and quality of canola, rape, and yellow mustard. Can. Entomol. 116:269-280.

Metcalf, R. L. and R. A. Metcalf. 1993. Destructive and useful insects: Their habits and control. McGraw-Hill, New York. 981 pp.

National Academy of Science. 1969. Chemical attractants and insect behavior. Pp. 290-309. *In* Principles of Plant and Animal Pest Control. Vol. 3.

Pimentel, D. 1961a. The influence of plant spatial patterns on insect populations. Ann. Entomol. Soc. Amer. 54: 323-333.

Pimentel, D. 1961b. Species and insect outbreaks. Ann. Entomol. Soc. Amer. 54: 76-86.

Putnam, L. G. 1977. Responses of four *Brassica* crop species to attack by the crucifer flea beetle, *Phyllotreta cruciferae*. Can. J. Plant Sci. 57: 987-989.

Root, R. B. and J. O. Tahvanainen. 1969. Role of winter cress, *Barbarea vulgaris*, as a temporal host in the seasonal development of the crucifer fauna. Ann. Entomol. Soc. Amer. 62: 852-855.

CHAPTER II

HOST PLANT PREFERENCE

OF THE WESTERN CABBAGE FLEA BEETLE

INTRODUCTION

The western cabbage flea beetle, *Phyllotreta pusilla* Horn (Chrysomelidae: Coleoptera), is often the most important insect pest of brassica crops in the Rocky Mountain region (Chittenden and Marsh 1920). These crops are most vulnerable in the spring when adult flea beetles attack newly emerged seedlings. Flea beetle feeding results in chewed pits on the leaves and cotyledons that, when severe, can cause seedling mortality. Less severe feeding can cause delayed plant development and reduced height, yield, and produce quality at harvest. The larvae of *P. pusilla* feed on the root tissues of brassica plants with no apparent damage to plants (Chittenden and Marsh 1920).

The preferred hosts of *P. pusilla* are in the family Brassicaceae (= Cruciferae). This pest also attacks other vegetable crops and sugar beets. Its preferred food plants, however, are turnip (*Brassica rapa* L.), mustards (*Brassica.* spp.), and radish (*Raphanus spp.*). Other food plants attacked by *P. pusilla* include: horseradish (*Radicula armaracia* L.), cabbage (*B. oleracea* L.), cauliflower (*B. oleracea* ssp. *botrytis*), rape (*B. napus* L. ssp. *oleifera*), Chinese mustard (*B. juncea* (L.)), watercress (*Rorippa nasturtium-aquaticum* (L.)), beeplant (*Cleome serrulata* Pursh.), sweet alyssum (*Alyssum maritimum* L.), candytuft (*Iberis* spp.), peppergrass (*Lepidium* spp.), hedge mustard (*Sisymbrium* spp.), and tansy mustard (*Descurainia pinnata* (Walter)) (Chittenden and Marsh 1920).

Recent detailed studies on the effects of *P. pusilla* on cabbage and other brassica crops have not been conducted. Thus, one objective of this study was to quantify the degree of flea beetle feeding on different brassica crops and different cultivars among *Brassica* species with emphasis on those crops most commonly cultivated. Feeny et al. (1970), sampling plants belonging to 23 different families, reported that adults of the cabbage flea beetles *P. cruciferae* (Goeze) and the striped flea beetle *P. striolata* (F.) have a narrow host range. This was restricted among the plants tested to the families Capparidaceae, Brassicaceae (=Crucifereae), and Tropaeolaceae. Similarly, Hicks (1972) tested the food plant preference of the *P. cruciferae* and *P. striolata* and reported that of 12 plant species of seven families in the field and 55 species of 31 families in the laboratory, only plants belonging to Capparaceae, Brassicaceae, Tropaeolaceae, and Limnanthaceae families were attacked by adults of both species.

It seems that feeding of these beetles is confined to plant species that contain glucosinolates as secondary plant compounds, which are thioglucosides found in almost all members of the family Brassicaceae (Feeny et al. 1970, Nielsen 1977, 1989, Rodman and Chew 1980, Louda and Mole 1991). In mustard, for example, mustard oil derived from glucosinolates impart a desirable pungent odor and taste, whereas in other crops (e.g., oilseed rape) glucosinolates and their breakdown products are deleterious within the extracted meal and have now been largely removed by plant breeding. Of more than 200 brassica species analyzed, almost all have thioglucosides (Kjaer 1963). In addition to the Brassicaceae, plants in 10 other families are known to have thioglucosides: Capparaceae, Resedaceae, Tovariaceae, Moringaceae, Limanthaceae, Tropaeolaceae, Caricaceae, Euphorbiaceae, Gyrostemonaceae, and Salvadoraceae (Ettlinger and Kjaer 1968, Larsen 1981). It has been documented that flea beetles, cabbage stem flea beetle, *Psylliodes chrysocephala* (L.) in particular, are attracted by isothiocyanates, hydrolysis products of glucosinolates released by brassica crops such as the oilseed rape (Bartlet et al. 1992).

The significance of mustard oil glucosides as attractants and of glucosinolates as feeding stimulants for specialized brassica feeding insect species has been acknowledged from the time of Verschaeffelt (1911) and since then has been well documented (Thorsteinson 1953, Wensler 1962, Nayar and Thorsteinson 1963, David and Gardiner 1966, Feeny et al. 1970, Hicks 1974, Nielsen 1978, Dilawari and Atwal 1987). However, host plant preference between flea beetles cannot be explained entirely in term of presence or absence of glucosinolates (Jonasson 1982, Larsen et al. 1985, Lamb, 1988). This is because flea beetles discriminate between different brassica species in a different manner. *Phyllotreta cruciferae*, for example, differentiate between brassica plants on the basis of the quality and quantity of glucosinolates present (Hicks 1974). Four other species of brassica feeding flea beetles, however, could not discriminate between different glucosinolates (Nielsen 1978). Explanation of this might be that flea beetles also respond to other groups of secondary plant compounds, which act either as additional feeding stimulants or as feeding deterrents. It has been noted that different classes of secondary plant compounds may have important antifeedant effects (Neilsen et al. 1977).

Glucosinolates in Brassicaceae contain a group of 80 thioglucosides that have side chains of varying structure (Larsen 1981, Rodman 1981) and, thus, varying effects upon organisms that come in contact with them or their breakdown products (Chew 1988). In this regard, glucosinolates in some brassica plants may not determine the feeding rate of the flea beetle, *P. cruciferae* (Bodnaryk and Palaniswamy 1990). Therefore, any interpretation for the putative effects of glucosinolates on insect feeding must be carefully assessed on a case-by-case basis (Chew 1988). In some cases (Bodnaryk 1991), the stage of host plant development, the concentration of a particular glucosinolate compound, and the insect species being considered, will effect the feeding behavior of the insect.

Higher levels of feeding by brassica feeding insects might be expected on plant tissue with high concentrations of glucosinolates. In laboratory tests, Bartlet et al. (1994) reported that glucosinolates stimulated the feeding of *P. chrysocephala* when added to agar and the amount of feeding that occurred increased with increasing glucosinolate concentrations. It has been documented that glucosinolates vary enormously in their occurrence, amount, concentration, and distribution within the plant (Sang et al. 1984, McGregor 1988). Thus, it is important to relate insect feeding with the quality and quantity of glucosinolates actually present in the plant tissues being consumed. It has been found that feeding damage of flea beetles of the genus *Phyllotreta* to rape cultivars with high or low glucosinolates has no correlation with the glucosinolate designation (Jonasson 1982, Larsen et al. 1985, Lamb 1988).

Bartlet and Williams (1991) testing the feeding acceptability of 40 different plants to *P. chrysocephala*, found that only glucosinolate-containing plants were accepted as food. When they added the glucosinolate sinigrin (allyl glucosinolate) to leaf discs of the rejected food plants, flea beetles did not accept them as food. Bartlet and Williams have also found that when solvent extracts of the rejected plants are applied to oilseed rape, feeding by adults is inhibited. They concluded that the feeding of *P. chrysocephala* is influenced by the presence or absence of glucosinolates, which may act as feeding stimulants, and other, unknown chemicals which act as feeding inhibitors.

Several studies were conducted to identify the feeding response of different brassica feeding flea beetles. Tokunaga and Kadowski (1949) studied the feeding response of *P. striolata* on 23 species of Brassicaceae and 19 species belonging to other families. They found that the beetles would attack only plant species belonging to Brassicaceae and Cucurbitaceae. The feeding preference of flea beetles, *P. cruciferae* and *P. striolata* in particular, with respect to various brassica species have been investigated in the United States and Europe (Newton 1928, Haddock 1945, Dobson 1956, Brett and Rudder 1966, Tahvanainen 1971).

Plant species of Brassicaceae and plant cultivars may differ in their susceptibility and attack by flea beetles. Flea beetles can discriminate between different oilseed rape cultivars (Brett and Rudder 1966, Putnam 1977, Lamb 1980, 1984, 1988, Lamb and Palaniswamy 1990, Bodnaryk and Lamb 1991) suggesting some kind of resistance in these cultivars that might be useful for controlling flea beetle damage in oilseed rape. Anderson et al. (1992) have conducted field and laboratory choice tests to determine the feeding preference of the flea beetle, *P. cruciferae*, for two oilseed rapes, *Brassica napus* (cv. 'Westar') and *B. campestris* L. (cv. 'Tobin'); white mustard, *Sinapis alba* L. (cv. 'Tilney'); and crambe, *Crambe abyssinica* Hochs (cv. 'Meyer'). They found that flea beetle feeding was significantly higher on oilseed rape than on the crambe and feeding damage was less on white mustard than on oilseed rape. They noticed that crambe did not inhibit flea beetle presence and feeding, and feeding pits were often shallow and smaller. They have suggested that crambe tissues may have a gustatory deterrent that inhibits further feeding. Their results demonstrated flea beetle resistance in crambe, and confirmed the reports of Putnam (1977) and Lamb (1984) on resistance in white mustard. Anderson and his group (1992) have also reported that *P. cruciferae* had the tendency to aggregate once feeding was initiated resulting in seedlings with extensive feeding on one cotyledon and little on the opposite cotyledon. This suggests that upon initiating feeding a flea beetle would influence the feedings of another flea beetles feeding.

Flea beetles may be selective in their choice of brassica hosts, suggesting that host plant selection can be modified by factors other than glucosinolate presence (Feeny et al. 1970). Morphological and physical characteristics (i.e., trichomes, surface waxes, silication, toughness, sclerotization, color, and shape) of brassica plants may effect herbivory by providing hostile·surfaces or by evoking altered host behavior (Norris and Kogan 1980). However, such discrimination has been attributed to the chemical composition and concentration of glucosinolates in the plant (Hicks 1974, Tahvanainen 1983). The glucosinolate composition of brassica plants changes with plant growth stage (Milford et al. 1989), with level of damage by flea beetles (Koristas et al. 1991), as well as with plant lines or cultivars (Bartlet et al. 1996). When testing eight oilseed rape lines in the field, Bartlet and his colleagues (1996) found that the concentration of isothiocyanate-releasing glucosinolates varies greatly, exhibiting a twenty-fold variation in concentration of these glucosinolates, whereas those tested in the laboratory exhibited little variation.

Chemically-based resistance in different brassica crops and their components (antixenosis, antibiosis or tolerance) to the western cabbage flea beetle is unknown. In a related species, *P. cruciferae*, it has been documented that the presence of high concentration of *p*-hydroxy-benzyl glucosinolate (sinalbin) in the cotyledons of young seedlings and in young leaves of the mustard, *Sinapis alba*, will deter the feeding of *P. cruciferae* (Bodnaryk 1991). Prior wounding as a result of insect feeding or mechanical damage also enhances the resistance to insect herbivores in some plants (Kogan and Paxton 1983, Karban and Myers 1989, Lin et al. 1990, Coleman and Jones 1991, Karabn 1991, Kogan and Fischer 1991, Tallamy and Raupp 1991). This can be attributed to chemical alterations as a result of wounding, leading to a decrease in the susceptibility or nutritional quality of wounded plants to the herbivores (Moran and Hamilton 1980, Kogan and Paxton 1983, Edwards et al. 1985, Haukioja and Neuvonen 1987, Lin et al. 1990).

Studies in this section of the research were conducted to investigate, by field and laboratory experiments, host plant preference of the western cabbage flea beetle when offered various brassica hosts. Such investigation may allow a tentative distinction between a mechanism of host plant selection and preference based on host plant physical and/or habitat characteristics, as well as a mechanism based on secondary plant compounds that may attract or repel the insect.

METHODS AND MATERIALS

Field Experiments

Host plant preference trials in the field were conducted at the Horticulture Field Research Center in Fort Collins, Colorado. Experiments were performed during the summer of 1996 and 1997 on naturally occurring populations. Individual plots consisted of single rows, 77-cm row spacing, each 7.5-m in length in 1996 and 6-m in length in 1997, arranged in a randomized complete block design with different brassica crops and different cabbage cultivars as treatments. Each study involved four replications. Brassica crops and cabbage cultivars were planted in the greenhouse for about 4 weeks prior to transplanting into the field. After transplanting into the field, plants were grown under standard husbandry practices and plots were kept weed-free. Because flea beetle adults are very active, especially in the middle of the day when it is warm and sunny, counting of flea beetles was done in early mornings when beetles are less active. Also efforts were made to avoid making noises and produce shadows upon plants to minimize flea beetle disturbance.

In 1996, two separate trials, each in a separate row, were conducted. The first trial included four different brassica crops: cabbage, *Brassica oleracea* L., cv. 'Golden Acre'; Chinese cabbage, *B. rapa* L ssp. *pekinensis*., cv. 'Michihili' (Lake Valley Seed Inc.); cauliflower, *B. oleracea* ssp. *botrytis*, cv. 'Snow Ball' (The Rocky Mountain Seed Co.); and Brussels sprouts, *B. oleracea* spp. *gemmifera*, cv. 'Long Island Improved' (Lake Valley Seed Inc.). The second trial included four different cabbage cultivars, 'Golden Acre', 'Copenhagen Market' (Lake Valley Seed Inc.), 'Chieftain Savoy', and 'Red Acre' (The

Rocky Mountain Seed Co.). Plants for each trial were transplanted on 13 May in 41-cm in-row spacing. Insect counts were made on 17, 21, and 30 May; 3, 6, 12, 18, and 26 June; and 3 and 11 July, by whole plant examination of 6 plants in the center of each plot.

In 1997, two trials were conducted. The first trial included eleven brassica crops: Chinese cabbage, cv. 'Michihili'; Brussels sprouts, cv. 'Long Island Improved'; mustard greens *B. juncea* (L.), cvs. 'Green Wave' and 'Florida Broadleaf'; collard, *B. oleracea* ssp. *acephala*, cv. 'Champion'; turnip, *B. campestris* ssp. *rapifera*, cvs. 'Purple Top White Globe' and 'Seven Top' (The Rocky Mountain Seed Co.); kale, *B. oleracea* ssp. *acephala*, cv. 'Dwarf Blue Curled Vates'; and broccoli raab, *Brassica rapa*, cv. 'Spring' (Lake Valley Seed Inc.). The second trial tested six different cabbage cultivars, 'Golden Acre', 'Copenhagen Market', 'Chieftain Savoy', 'Red Acre', 'Dynamo' (The Rocky Mountain Seed Co.), and 'Early Flat Dutch' (Lake Valley Seed Inc.). Plants for each trial were transplanted on 20 May in a 41-cm in-row spacing. Insect counts were made on 2, 6, 12, 16, and 23 June; and 2 July, by whole plant examination of 5 plants in the center of each plot.

Laboratory Experiments

Host plant preferences in the laboratory were conducted in the summer of 1997, using 12 different brassica crops, 11 cabbage cultivars, and 4 broccoli cultivars. Brassica crops included Chinese cabbage, cv. 'Michihili'; Brussels sprouts, cv. 'Long Island Improved'; mustard, cvs. 'Green Wave' and 'Florida Broadleaf'; collard, cv. 'Champion'; turnip, cvs. 'Purple Top White Globe' and 'Seven Top'; kale, cv. 'Dwarf Blue Curled

Vates'; broccoli raab, cv. 'Spring'); broccoli, *B. oleracea* ssp. *italica*, cv. 'Premium Crop'; cauliflower, cv. 'Snow Ball'; and Bok Choy, *B. juncea* L. ssp. *rugosa*, cv. 'Oriental Mustard Cabbage' (The Rocky Mountain Seed Co.). Cabbage cultivars included 'Golden Acre', 'Copenhagen Market', 'Chieftain Savoy', 'Red Acre', 'Dynamo', 'Early Flat Dutch', 'Hybrid Stonehead', 'Earliana', 'Fast Ball' (W. Atlee Burpee & Co.), 'Salad Delight', and 'Early Jersey Wakefield' (Week Seed Co.). Broccoli cultivars included 'Premium Crop', 'Green Goliath' (Henry Field Seed & Nursery Co.), 'Love Me Tender Hybrid' (W. Atlee Burpee & Co.), and 'Green Comet Hybrid' (Thompson & Morgan Inc.).

Tests were conducted using screened cages (35-cm wide by 68-cm high by 61-cm deep) with clear polystyrene tops. Cages were placed under wide-spectrum artificial lighting. Plants used in all trials were grown in flats in the greenhouse, watered as needed, and fertilized. Ten-day seedlings were used for each of the experiments. Before the transfer to the lab, seedlings with the media was transferred to 0.03 liter plastic cups (Prairie Packaging Inc.). Four seedlings of each crop/cultivar were placed randomly inside the cage. About 100 adult flea beetles were introduced into the cage and left to feed for 24 hours. Seedlings were then removed from the cage for feeding-preference evaluation. Insect feeding to seedlings was estimated by counting the flea beetle feeding holes produced in leaves. In each trial seedlings belonging to a crop/cultivar were replicated four times (4 seedlings per crop/cultivar) and repeated three times (three different test dates).

To examine the effects of host plant on the colonization and infestation of western cabbage flea beetle, data were analyzed with two-way ANOVA (SAS institute 1985), testing for effects of host plant and block. Analyses were carried out on the mean number of flea beetles per plant for each treatment for each block. Comparisons of host plants were carried out using Student-Newman-Keuls (SNK) (SAS institute 1985).

RESULTS AND DISCUSSION

Field Experiments

In the 1996 evaluations (Table 2.1), the number of flea beetles observed was significantly different among brassica crops ($P<0.05$). Chinese cabbage was significantly the most attractive to flea beetles on all, except on the 30-May, sampling dates ($F=5.40$, $P=0.0211$; $F=8.48$, $P=0.0055$; $F=2.34$, $P=0.1421$; $F=30.70$, $P=0.0001$; $F=26.83$, $P=0.0001$; $F=11.03$, $P=0.0023$; $F=61.48$, $P=0.0001$; $F=9.04$, $P=0.0044$; $F=62.86$, $P=0.0001$; $F=7.60$, $P=0.0077$, respectively). Cauliflower, Brussels sprouts and cabbage were significantly less attractive to flea beetles compared to Chinese cabbage. In the 1997 evaluations (Table 2.2), the number of flea beetles observed was significantly different among brassica crops ($P<0.05$). Again, Chinese cabbage, as well as mustards, and broccoli raab were significantly most attractive to flea beetles on most sampling dates ($F=6.75$, $P=0.0001$; $F=13.67$, $P=0.0001$; $F=4.67$, $P=0.0019$; $F=4.45$, $P=0.0021$; $F=4.79$, $P=0.0013$; $F=45.57$, $P=0.0001$, respectively). Collards, kale and Brussels sprout were significantly less attractive to flea beetles.

Table 2.1. Mean number of western cabbage flea beetles per plant observed on different brassica crops, Colorado State University Horticulture Field Research Center, Fort Collins, Colorado, 1996.

Brassica Crops	Mean number of flea beetles / plant[a]									
	17-May	21-May	30-May	3-Jun	6-Jun	12-Jun	18-Jun	26-Jun	3-Jul	12-Jul
Cabbage (cv. Golden Acre')	0.54 b	0.08 b	2.83 a	4.17 b	3.17 b	8.58 b	15.17 b	7.00 b	3.08 b	1.54 b
Chinese Cabbage (cv. 'Michihili')	2.42 a	0.75 a	4.38 a	9.67 a	7.17 a	16.88 a	62.21 a	21.54 a	29.58 a	8.25 a
Cauliflower (cv. 'Snow Ball')	0.50 b	0.17 b	1.71 a	2.33 b	1.42 c	6.00 b	12.00 b	7.88 b	3.83 b	1.96 b
Brussels Sprouts (cv. 'Long Island Improved')	1.00 b	0.17 b	2.58 a	3.33 b	1.54 c	6.13 b	11.25 b	3.92 b	2.33 b	0.92 b

[a]Means within a column followed by the same letter are not significantly different (P=0.05) by SNK test. Means based on 6 plants per plot for 4 replications.

Table 2.2. Mean number of western cabbage flea beetles per plant observed on different brassica crops, Colorado State University Horticulture Field Research Center, Fort Collins, Colorado, 1997.

Brassica Crops	Mean number of flea beetles / plant[a]					
	2-Jun	6-Jun	12-Jun	16-Jun	23-Jun	2-Jul
Chinese cabbage (cv. 'Michihili')	6.20 ab	4.10 bc	12.80 a	16.90 a	21.80 a	43.60 a
Brussels Sprouts (cv. 'Long Island Improved')	3.40 b	2.45 c	4.60 b	6.25 b	7.10 bc	1.95 c
Mustard (cv. 'Green Wave')	9.90 a	8.85 a	17.30 a	22.20 a	13.25 ab	13.25 b
Mustard (cv. 'Florida Broadleaf')	9.70 a	9.05 a	17.93 a	20.00 a	26.75 a	9.85 b
Collard (cv. 'Champion')	3.60 b	2.80 c	4.30 b	5.50 b	6.63 bc	1.25 c
Turnip (cv. 'Purple Top White Globe')	5.90 ab	4.10 bc	13.51 a	14.30 a	10.94 abc	12.05 b
Turnip (cv. 'Seven Top')	5.90 ab	5.45 ab	13.90 a	11.50 a	14.75 ab	12.70 b
Kale (cv. 'Dwarf Blue Curled Vates')	3.25 b	2.80 c	8.10 ab	5.50 b	5.25 c	0.90 c
Broccoli Raab (cv. 'Spring')	8.60 a	8.40 a	17.40 a	17.00 a	23.44 a	8.25 b

[a]Means within a column followed by the same letter are not significantly different (*P*=0.05) by SNK test. Means based on 5 plants per plot for 4 replications.

In the 1996 evaluations of cabbage cultivars (Table 2.3), the number of flea beetles observed was significantly different on the 3, 6, and 18 June sampling dates (F=5.99, P=0.0158; F=37.76, P=0.0001; F=9.32, P=0.004, respectively). The cultivars 'Red Acre' and 'Chieftain Savoy' were significantly less attractive to flea beetles, while the cultivars 'Golden Acre' and 'Copenhagen Market' were significantly the most attractive to flea beetles. On sampling dates 17, 21 and 30 May, 12 and 26 June, and 3 and 12 July, there were no significant differences in the number of flea beetles colonizing different cabbage cultivars (F=0.58, P=0.6417; F=1.72, P=0.2323; F=2.39, P=0.1368; F=3.08, P=0.0827; F=1.90, P=0.1995; F=2.88, P=0.0956; F=0.39, P=0.7632, respectively). In the 1997 cabbage cultivars preference evaluations (Table 2.4), numbers of flea beetles again were significantly different among the cabbage cultivars studied ($P<0.05$). 'Copenhagen Market', 'Dynamo' and 'Golden Acre' were significantly more attractive to flea beetles on 12 and 23 June (F=4.05, P=0.0158; F=3.14, P=0.0296, respectively) than cultivars 'Red Acre' and 'Early Flat Dutch'. On the 2 July sampling date, only the cultivar 'Copenhagen Market' was significantly more attractive to flea beetles (F=3.55, P=0.0256) than other cabbage cultivars. There were no significant differences in the number of flea beetles colonizing cabbage cultivars on the 2, 6, and 16 June sampling dates (F=0.65, P=0.6674; F=1.27, P=0.3261; F=3.40, P=0.0298, respectively).

Table 2.3. Mean number of western cabbage flea beetles per plant observed on different cabbage cultivars, Colorado State University Horticulture Field Research Center, Fort Collins, Colorado, 1996.

Cabbage Cultivars	Mean number of flea beetles / plant[a]									
	17-May	21-May	30-May	3-June	6-June	12-June	18-June	26-June	3-July	11-July
Golden Acre	0.21 a	0.00 a	2.88 a	5.38 a	3.67 a	8.50 a	12.17 a	5.67 a	3.17 a	1.08 a
Copenhagen Market	0.46 a	0.17 a	4.38 a	6.08 a	2.96 a	8.04 a	11.63 a	4.62 a	3.83 a	0.88 a
Chieftain Savoy	0.37 a	0.04 a	2.25 a	3.21 b	0.50 b	4.96 a	7.54 b	4.29 a	2.29 a	0.71 a
Red Acre	0.50 a	0.17 a	2.54 a	2.33 b	1.25 b	5.92 a	6.08 b	3.42 a	1.42 a	0.79 a

[a]Means within a column followed by the same letter are not significantly different (P=0.05) by SNK test. Means based on 6 cabbage plants per plot for 4 replications.

Table 2.4. Mean number of western cabbage flea beetle per plant observed on different cabbage cultivars, Colorado State University Horticulture Field Research Center, Fort Collins, Colorado, 1997.

Cabbage Cultivars	Mean number of flea beetles / plant[a]					
	2-Jun	6-Jun	12-Jun	16-Jun	23-Jun	2-Jul
Golden Acre	3.40 a	2.80 a	8.90 a	9.25 a	10.25 ab	3.35 ab
Copenhagen Market	3.25 a	1.80 a	10.10 a	8.90 a	13.70 a	4.40 a
Chieftain Savoy	2.90 a	1.45 a	6.15 ab	8.95 a	10.60 a	2.85 ab
Red Acre	2.45 a	2.20 a	4.85 b	5.20 a	4.90 b	1.35 ab
Dynamo	3.75 a	2.30 a	9.85 a	9.15 a	11.65 a	3.10 ab
Early Flat Dutch	2.90 a	3.05 a	5.50 ab	5.15 a	6.19 ab	0.60 ab

[a]Means within a column followed by the same letter are not significantly different (P=0.05) by SNK test. Means based on 6 cabbage plants per plot for 4 replications.

Laboratory Experiments

In the laboratory evaluation of brassica crops (Table 2.5), the number of flea beetle feeding holes was significantly different among cruciferous crops ($P<0.05$). The number of feeding holes produced was significantly higher in Chinese cabbage on 25 and 26 June (F=6.49, P=0.0001; F=6.08, P=0.0001) compared to Brussels sprouts, cauliflower, broccoli, collard, kale, and mustard (cv. 'Green Wave'). On the 27 June sampling date, Chinese cabbage and turnip (cv. 'Seven Top') had a significantly higher number of feeding holes (F=3.38, P=0.0032) than Brussels sprouts and broccoli.

In the laboratory evaluation of cabbage cultivars (Table 2.6), the number of flea beetle feeding holes was not significantly different among cabbage cultivars on all sampling dates (F=0.85, P=0.5860; F=1.59, P=0.1571; F=0.37, P=0.9495, respectively). In the broccoli cultivars evaluation (Table 2.7), the number of flea beetles holes was not significantly different among broccoli cultivars ($P>0.05$) except on the 16 July sampling date (F=7.25, P=0.009). 'Green Goliath' cultivar had a significantly higher number of flea beetle feeding holes than the 'Love Me Tender Hybrid' cultivar.

Table 2.5. Mean number of flea beetle feeding holes per plant on different brassica crops. laboratory study, 1997.

Brassica Crops	Mean number of feeding holes / plant[a]		
	25-Jun	26-Jun	27-Jun
Chinese Cabbage (cv. 'Michihili')	50.25 a	92.00 a	40.50 a
Cauliflower (cv. 'Snow Ball')	1.25 c	8.25 c	3.75 ab
Brussels Sprouts (cv. 'Long Island Improved')	1.00 c	0.25 c	1.0 b
Mustard (cv. 'Green Wave')	11.75 c	35.50 bc	24.50 ab
Mustard (cv. 'Florida Broadleaf')	15.75 bc	36.50 bc	31.25 ab
Collard (cv. 'Champion')	1.50 c	2.00 c	8.50 ab
Turnip (cv. 'Purple Top White Globe')	40.25 ab	35.00 bc	23.25 ab
Turnip (cv. 'Seven Top')	21.00 bc	64.50 ab	40.25 a
Kale (cv. 'Dwarf Blue Curled Vates')	2.50 c	1.75 bc	5.50 ab
Broccoli Raab (cv. 'Spring')	15.75 bc	60.25 ab	16.25 ab
Bok Choy (cv. 'Oriental Mustard Cabbage')	32.25 abc	32.00 bc	18.00 ab
Broccoli (cv. 'Premium Crop')	1.25 c	0.75 c	2.25 b

[a]Means within a column followed by the same letter are not significantly different (P=0.05) by SNK test. Means based on 4 cabbage plants per cage for 4 replications.

Table 2.6. Mean number of flea beetle feeding holes per plant on different cabbage cultivars, laboratory study, 1997.

Cabbage Cultivars	Mean number of feeding holes / plant[a]		
	16-Jul	17-Jul	18-Jul
Golden Acre	3.00 a	13.00 a	6.25 a
Copenhagen Market	4.00 a	29.50 a	4.75 a
Chieftain Savoy	14.50 a	3.00 a	3.50 a
Red Acre	4.25 a	7.00 a	1.50 a
Dynamo	6.25 a	5.75 a	6.00 a
Early Flat Dutch	7.75 a	9.25 a	7.75 a
Hybrid Stonehead	5.25 a	2.25 a	5.25 a
Earliana	3.50 a	4.25 a	2.50 a
Salad Delight	2.00 a	3.75 a	2.75 a
Early Jersey Wakefield	9.50 a	12.00 a	4.00 a
Fast Ball	5.75 a	9.50 a	8.25 a

[a]Means within a column followed by the same letter are not significantly different (P=0.05) by SNK test. Means based on 4 cabbage plants per cage for 4 replications.

Table 2.7. Mean number of flea beetle feeding holes per plant on different broccoli cultivars, laboratory study, 1997.

Broccoli Cultivars	Mean number of feeding holes / plant[a]		
	16-Jul	17-Jul	18-Jul
Premium Crop	12.50 bc	5.50 a	2.50 a
Green Goliath	37.25 a	6.75 a	3.25 a
Love Me Tender Hybrid	5.75 c	10.50 a	3.00 a
Green Comet Hybrid	28.00 ab	1.75 a	2.50 a

Means within a column followed by the same letter are not significantly different (P=0.05) by SNK test. Means based on 4 cabbage plants per cage for 4 replications.

Among the brassica crops tested, Chinese cabbage sustained higher flea beetle density in the field than the other brassica crops. Chinese cabbage also was more preferred in the laboratory choice tests than the other tested crops. Compared to Chinese cabbage, cauliflower, Brussels sprouts and cabbage were less preferred by flea beetles in the field tests, and Brussels sprouts, cauliflower, broccoli, collard and kale were less preferred in the laboratory choice tests.

Among the cabbage cultivars tested, cultivars 'Golden Acre' and 'Copenhagen Market' sustained higher flea beetle density in the field trials. 'Copenhagen Market' also had the highest number of feeding holes in the laboratory choice tests. 'Red Acre', on the other hand, was less preferred by flea beetles in the field trials. Cabbage cultivars. 'Earliana' and 'Salad Delight' also showed less feeding than other cultivars in the laboratory choice tests. Among the broccoli cultivars, 'Green Goliath' had the highest number of feeding holes; 'Love Me Tender Hybrid' and 'Premium Crop' were least preferred.

The above results demonstrate discrimination by flea beetles between crops and cultivars tested. Field and laboratory trials showed analogous feeding preference by flea beetles. The least preferred plants received low flea beetle colonization in the field and low feeding damage in the laboratory. These plants may possess chemical or physical attributes that make them distasteful and non-preferred, suggesting some type of resistance. Given the higher level of flea beetle density and higher level of feeding in both field and laboratory tests, Chinese cabbage, 'Golden Acre' and 'Copenhagen Market' cabbages and broccoli cultivar 'Green Goliath' have features of little resistance to feeding by *P. pusilla*.

Although no attempt was made to extract and identify secondary plant compounds that may act as feeding deterrents, some suggestion as to their identity can be made based on what is already known of the secondary chemistry of these plants. For example, candytuft, *Iberis amara*, contains cucurbitacins that inhibit feeding by the striped turnip flea beetle, *Phyllotreta nemorum* L. (Nielsen 1978, 1989, Nielsen et al. 1977). Wallflower, *Erysinum* spp., and the English wallflower, *Cheiranthus* spp., contain cardiac glycosides that are feeding inhibitors for some chrysomelid flea beetles (Nielsen 1978, 1989). The money plant, *Lunaria annua* L., and shepherd's purse, *Capsella bursa-pastoris* (L.), contain both alkaloids and saponins that are feeding deterrents for *P. nemorum* (Nielsen 1989). All these plant species similarly belong to the Brassicaceae.

Epicuticular wax layer covering leaf surfaces in Brassicaceae species also may influence the rate and pattern of feeding of flea beetles. This was evident when *P. cruciferae* was offered different cultivars with different wax levels (Bodnaryk 1992). Polishing waxy leaves can also affect the feeding behavior of flea beetle by destroying the ordered physical structure of surface waxes (Holloway et al. 1977, Jeffree 1986, Conn and Tewari 1989). *P. cruciferae* feeding was much lower when offered cultivars with waxy leaves, and was high when fed upon cultivars with non-waxy leaves. Bodnaryk (1992) reported that *B. oleraceae* plants, cauliflower, cabbage, Brussels sprouts and broccoli, have waxy leaves and are fed upon at much lower rates than non-waxy mustards, *Sinapis alba*, *S. arvensis* and *B. nigra*. It has been noted that the mustard *S. alba* received the highest feeding rate, though was able to tolerate flea beetle feeding

(Putnam 1977, Lamb 1984, Bodnaryk and Lamb 1991, Bodnaryk 1992) and, thus, has the potential to be used as a trap crop (Kloen and Altieri 1990) in brassica crop plantings where flea beetles are problematic. Altering the amount, type or physical structure of the epicuticular wax layer, through conventional breeding methods or genetic engineering, may enhance brassica crop resistance against flea beetles.

Adult *P. pusilla* may use many chemical, visual, and tactile cues in their feeding response to plants. It is possible that seedlings of the most preferred *Brassica* species were eaten by *P. pusilla* because they lack feeding deterrents or have high levels of feeding stimulants. In their report, Bartlet and Williams (1991) listed some plants that contain glucosinolates and are fed upon by *P. chrysocephala*. The above results showed that Chinese cabbage had the highest adult feeding compared to the other plant species tested, which suggests the presence of glucosinolates in the plant, and that glucosinolates are also essential feeding stimulants for *P. pusilla*.

Adult flea beetles appear to require a feeding stimulant as well as a long-range olfactory response to mustard oils. Glucosinolates are responsible for host selection by brassica feeding flea beetles, with the volatile product metabolites of glucosinolates (e.g., allyl isothiocynate) acting as "long range" attractants and the glucosinolates themselves acting as feeding stimuli (Feeny et al. 1970). When *P. cruciferae* adults were provided with bean leaves that been cultured for several hours in diluted aqueous solution of sinigrin, the leaves were readily fed upon; bean leaves that were cultured in distilled water were not attacked. However, *P. cruciferae* did not feed on the brassica species candytuft, shepherd's purse, and wormseed-mustard though thioglucosides have been found in these species (Kjaer 1960). It seems that these plants lack some component essential for feeding response by *P. cruciferae* or that they may contain inhibitory components that prevail over those responsible for attraction.

The western cabbage flea beetle showed feeding and plant preference within the Brassicaceae based on quantitative measures of the number of beetles observed on seedlings in the field and the amount of feeding holes counted on seedlings in the laboratory. These results support the hypothesis that *P. pusilla* utilizes brassica crops differently and host preference is indeed a potential factor in this selection. From beetle counts and feeding hole counts, western cabbage flea beetle showed host plant preference that corresponded to its feeding preference. In other words, plant species in the field that were observed to have higher number of flea beetles, received higher feeding damaged in the laboratory (i.e., preferred), and plant species that had lower flea beetle colonization in the field were less damaged in the laboratory (i.e., non-preferred).

REFERENCES CITED

Anderson, M. D., C. Peng, and M. J. Weiss. 1992. Crambe, *Crambe abyssinica* Hochst., as a flea beetle resistant crop (Coleoptera: Chrysomelidae). J. Econ. Entomol. 85: 594-600.

Bartlet, E. and I. H. Williams. 1991. Factors restricting the feeding of the cabbage stem flea beetle (*Psylliodes chrysocephala*). Entomol. Exp. Appl. 60: 233-238.

Bartlet, E., I. H. Williams, M. M. Blight and A. J. Hick. 1992. Responses of the oilseed rape pests *Ceutorhynchus assimilis* and *Psylliodes chrysocephala* to a mixture of isothiocyanate. Pp. 103-104. *In* S. B. J. Menken, J. H. Visser and P. Herrewijn (eds.), Proceeding of the 8th International Symposium on Insect-Plant Relationships. Kluwer Academic Publisher, Dordrecht, The Netherlands.

Bartlet, E., D. Parsons, I. H. Williams and S. J. Clark. 1994. The influence of glucosinolates and sugars on feeding by the cabbage stem flea beetle, *Psylliodes chrysocephala*. Entomol. Exp. et Appl. 73: 77-83.

Bartlet, E., R. Mithen and S. J. Clark. 1996. Feeding of the cabbage stem flea beetle *Psylliodes chrysocephala* on high and low glucosinolate cultivars of oilseed rape. Entomol. Exp. et Appl. 80: 87-89.

Bodnaryk, R. P. 1991. Developmental profile of sinalbin (*p*-hydroxybenzyl glucosinolate) in mustard seedlings, *Sinapis alba* L, and its relationship to insect resistance. J. Chem. Ecol. 17: 1543-1556.

Bodnaryk, R. P. 1992. Leaf epicuticular wax, an antixenotic factor in Brassicaceae that effects the rate and pattern of feeding of flea beetles, *Phyllotreta cruciferae* (Goeze). Can. J. Plant Sci. 72: 1295-1303.

Bodnaryk, R. P. and R. J. Lamb. 1991. Mechanisms of resistance to the flea beetle, *Phyllotreta cruciferae* (Goeze) in mustard seedlings, *Sinapis alba* L. Can. J. Plant Sci. 71: 13-20.

Bodnaryk, R. P. and P. Palaniswamy. 1990. Glucosinolate levels in the cotyledons of mustard, *Brassica juncea* L and rape, *B. napus* L do not determine feeding rates of the flea beetle, *Phyllotreta cruciferae* (Goeze). J. Chem. Ecol. 16: 2735-2746.

Brett, C. H. and J. D. Rudder. 1966. Resistance of 30 commercial cruciferous varieties to the striped flea beetle, *Phyllotreta striolata*. J. Econ. Entomol. 59: 769.

Chew, F. S. 1988. Searching for defensive chemistry in the cruciferae, or, do glucosinolates always control interactions of Cruciferae with their potential behaviors and symbionts? No. 1, pp. 81-112. *In* K. C. Spencer (ed.). chemical Mediation of Coevolution. Academic Press. Toronto.

Chittenden, F. H. and H. O. Marsh. 1920. The western cabbage flea beetle. USDA, Bulletin No. 902. 21 pp.

Coleman, J. S., and C. G. Jones. 1991. A phytocentric perspective of phytochemical induction by herbivores. Pp. 3-45. *In* Tallamy, D. W. and M. J. Raupp (eds.), Phytochemical induction by herbivores. John Wiley & Sons, New York, NY. 431 pp.

Conn, K. L. and J. P. Tewari. 1989. Ultrastructure of epicuticular wax in canola. Z. Naturforsch. Teil C 44: 705-711.

David, W. A. L. and B. O. C. Gardiner. 1966. The effect of sinigrin on the feeding of *Pieris brassicae* L. larvae transferred from various diets. Entomol. Exp. App. 9: 95-98.

Dilawari, V. K. and A. S. Atwal. 1987. Effect of cruciferous glucosinolates on probing pattern and feed uptake by mustard aphid, *Lipaphis erysimi* (Kaltenbach). Proc. Indiana Acad. Sci. (Anim. Sci.) 96: 695-703.

Dobson, R. N. 1956. A note on the relative abundance of flea beetles (*Phyllotreta* Stephens and *Phyllotreta* Berthold) on different cruciferous crops. J. Hort. Sci. 51: 291-294.

Edwards, P. J., S. D. Wratten, and H Cox. 1985. Wound-induced changes in the acceptability of tomato to larvae of *Spodoptera littoralis*: A laboratory bioassay. Ecolo. Entomol. 10: 155-158.

Ettlinger, M. G. and A. Kjaer. 1968. Sulfur compounds in plants. Pp. 59-144. *In* T. J. Mabry, R. E. Alston, and V. C. Runeckles (eds.), Recent Advances in Phytochemistry. Vol. I. Appleton-Century-Crofts, New York.

Feeny, P., K. L. Paauwe, and N. J. Demong. 1970. Flea beetles and mustard oils: host plant specificity of *Phyllotreta cruciferae* and *P. striolata* adults (Coleoptera: Chrysomelidae). Ann. Entomol. Soc. Am. 63: 832-841.

Haddock, M. J. 1945. Observations on the species of flea beetles infesting *Brassica* crops in the west of England. Rep. Agric. Hort. Res. Stn. Univ. Bristol: 166-169.

Haukioja, E. and S. Neuvonen. 1987. Insect population dynamics and induction of plant resistance: The testing of hypothesis. Pp. 411-432. *In* P. Barbosa and J. C. Schultz (eds.), Insect Outbreaks. Academic Press, New York, NY. 578 pp.

Hicks, K. P. 1972. Host plant and habitat selection by crucifer feeding flea beetles (Coleoptera: Chrysomelidae). Ph.D. Thesis. Cornell University. 151 pp.

Hicks, K. L.1974. Mustard oil glycosides; feeding stimulants for adult cabbage flea beetles, *Phyllotreta cruciferae*. Ann. Entomol. Soc. Am. 67(2): 261-264.

Holloway, P. J., G. A. Brown, E. A. Baker and M. J. K. Macey. 1977. Chemical composition and ultrastructure of the epicuticular wax in three lines of *Brassica napus* (L.). Chem. Phys. Lipids 19: 114-127.

Jeffree, C. E. 1986. The cuticle, epicuticular waxes and trichomes of plants, with references to their structure, function and evolution. Pp. 23-64. In B. Juniper and R. Southwoods (eds.), Insects and the Plant Surface. Edward Arnold, London, UK.

Jonasson, T. 1982. Naringsgnag av jordlopper pa tva varrapssorter med olika glukosinolathalt. Entomol. Tidskr. 103: 140-142.

Karban, R. 1991. Induced resistance in agricultural systems. Pp. 403-419. *In* D. W. Tallamy and M. J. Raupp (eds.), Phytochemical induction by herbivores. John Wiley & Sons, New York, NY. 431 pp.

Karban, R., and J. H. Myers. 1989. Induced plant responses to herbivory. Ann. Rev. of Ecol. and Sys. 20: 331-348.

Kjear, A. 1963. Naturally derived isothiocyanates (mustard oils) and their parent glucosides. Fortschr. Chem. Org. Naturst. 18: 122.

Kloen, H. and M. A. Altieri. 1990. Effect of mustard (*Brassica hirta*) as a non-crop plant on competition and insect pests in broccoli (*Brassica oleracea*). Crop Protection 9: 90-96.

Kogan, M. and D. C. Fischer. 1991. Inducible defenses in soybean against herbivorous insects. Pp. 347-378. *In* D. W. Tallamy and M. J. Raupp (eds.), Phytochemical induction by herbivores. John Wiley & Sons, New York, NY. 431 pp.

Kogan, M. and J. Paxton. 1983. Natural inducers of plant resistance to insects. *In* P. A. Hedin, (ed.) Plant resistance to insects. ASC Symposium Series 208: 153-171.

Koritsas, V. M., J. A. Lewis and G. R. Fenwick. 1991. Glucosinolate responses of oilseed, mustard and kale to mechanical wounding and infestation by cabbage stem flea beetles. Ann. Appl. Biol. 118: 209-221.

Lamb, R. J. 1980. Hairs protect pods of mustard (*Brassica Hirta* 'Gisilba') from flea beetle feeding damage. Can. J. Plant Sci. 60: 1439-1440.

Lamb, R. J. 1984. Effects of flea beetles, *Phyllotreta* spp. (Chrysomelidae: Coleoptera, on the survival, growth, seed yield, and quality of canola, rape, and yellow mustard.

Can. Entomol. 116:269-280.

Lamb, R. J. 1988. Susceptibility of low and high glucosinolate oilseed rapes to damage by flea beetles, *Phyllotreta* spp. (Coleoptera: Chrysomelidae). Can. Entomol. 120: 195-169.

Lamb, R. J and P. Palaniswamy. 1990. Host discrimination by a crucifer-feeding flea beetle, *Phyllotreta striolata* (F.) (Coleoptera: Chrysomelidae). Can. Entomol. 122: 817-824.

Larsen, P. O. 1981. Glucosinolates. Pp. 501-525. In EE Conn (ed.), The Biochemistry of Plants, Vol. 7. Academic Press, Toronto.

Larsen, L., J. K. Nielsen, A. Ploger, and H. Sorensen. 1985. Responses of some beetle species to varieties of oilseed rape and to pure glucosinolates. Pp. 230-244. *In* H. Sorensen (ed.), Advances in the production and Utilization of Cruciferous crops. Martinus Nijhoff/Dr. W. Junk Publishers, Dordrecht.

Lin, H., M. Kogan, and D. Fischer. 1990. Induced resistance in soybean to the Mexican bean beetle (Coleoptera: Coccinellidae). Comparisons of inducing factors. Environ. Entomol. 19: 1852-1857.

Louda, S. and S. Mole. 1991. Glucosinolates: chemistry and ecology. Pp. 123-64. *In* G. A. Rosenthal and M. R. Berenbaum (eds.), Herbivores and their interactions with secondary plant metabolites 2E (1): chemical participants. New York: Academic Press.

McGregor, D. I. 1988. Glucosinolate content of developing rapeseed (*Brassica napus* L. Midas) seedling. Can. J. Plant Sci. 68: 367-380.

Milford, G. F. J., K. Fieldsend, A. J. R. Porter and C. J. Rawlinson. 1989. Changes in glucosinolate concentration during the vegetative growth of single and double low cultivars of winter oilseed rape. Aspects of Appl. Biol. 23: 83-90.

Moran, N. and W. Hamilton. 1980. Low nutritive quality as defense against herbivores. Journal of Theoretical Biology 80: 247-254.

Nayar, J. K. and A. J. Thorsteinson. 1963. Further investigations into the chemical basis of insect-host plant relationships in an oligophagous insect, *Plutella maculipennis* (Curtis) (Lepidoptera: Plutellidae). Can. J. Zool. 41: 923-929.

Nielsen, J. K. 1977. Host plant relationships of *Phyllotreta nemorum* L. (Coleoptera: Chrysomelidae). I. Field studies. Z. Angew. Entomol. 84: 396-407.

Nielsen, J. K. 1978. Host plant discrimination within Cruciferae: Feeding responses of four leaf beetles (Coleoptera: Chrysomelidae) to glucosinolates, cucurbitacins and cardenolides. Entomol. exp. et Appl. 24: 41-54.

Nielsen, J. K. 1989. Host plant relationships of *Phyllotreta nemorum* L. (Coleoptera: Chrysomelidae). II. Various defensive mechanisms in plants and their role in determining the host plant range. J. Applied Entomol. 107: 193-202.

Nielsen, J. K., L. M. Larsen and H. Sorenson. 1977. Cucurbitacin E and I in *Iberis amara*: Feeding inhibitors for *Phyllotreta nemorum*. Phytochemistry 16: 1519-1522.

Newton, H. C. F. 1928. The biology of flea-beetles (*Phyllotreta*) attacking cultivated Cruciferae. J1. S. East Agric. Coll. Wye. 25: 90-115.

Norris, D. M. and M. Kogan. 1980. Biochemical and morphological basis of resistance. Pp. 23-61. *In* F. G. Maxwell and PR Jennings (eds.), Breeding Plants Resistant to Insects. John Wiley and Sons, Toronto. Ontario.

Putnam, L. G. 1977. Responses of four *Brassica* crop species to attack by the crucifer flea beetle, *Phyllotreta cruciferae*. Can. J. Plant Sci. 57: 987-989.

Rodman J. E. 1981. Divergence, convergence, and parallelism in phytochemical characters. The glucosinolate-myrosinase system. Pp. 43-79. *In* D. A. Young and D. A. Seigler (eds.). Phytochemistery and Angiosperm Phylogeny. Praeger, New York.

Rodman, J. E. and F. S. Chew. 1980. Phytochemical correlates of herbivory in a community of native and naturalized Cruciferae. Biochemical Systematics and Ecology 8: 43-50.

Sang, J. P., I. R. Minchinton, P. K. Johnstone and R. J. W. Tuscott. 1984. Glucosinolate profiles in the seed, root and leaf tissue of cabbage, mustard, rapeseed, radish and swede. Can. J. Plant Sci. 64: 77-93.

SAS Institute. 1985. SAS user's guide: Statistics, 5th ed. SAS Institute, Cary, NC.

Tahvanainen, J. O. 1971. Population biology of crucifer feeding flea beetles (Coleoptera: Chrysomelidae). Ph.D. Thesis. Cornell University. 106 pp.

Tahvanainen, J. O. 1983. The relationship between flea beetles and their cruciferous host plants: the role of plant and habitat characteristics. Oikos 40: 433-437.

Tallamy, D. W. and M. J. Raupp. 1991. Phytochemical Induction by Herbivores. John Wiley & Sons, New York, NY. 431 pp.

Thorsteinson, A. J. 1953. The chemotactic responses that determine host specificity in an oligophagous insect (*Plutella maculipennis* (Curt.) Lepidoptera). Can. J. Zool. 31:

52-72.

Tokunaga, M. and S. Kadowski. 1949. Studies on the life history and bionomics *of Phyllotreta vittata.* Feeding habits of imaginal insects. Trans. Kansai. Entomol. Soc. 14 (2):59-69, 15 (1): 63-72, 15 (2): 61-68.

Verschaeffelt, E. 1911. The cause determining the selection of food in some herbivorous insects. Proc. Acad. Sci. Amsterdam 13:536-542.

Wensler, R. J. D. 1962. Mode of host selection by an aphid. Nature 195: 830-831.

CHAPTER III

EFFECTS OF HOST PLANT DENSITY AND INTERPLANTING ON THE POPULATION DENSITY OF THE WESTERN CABBAGE FLEA BEETLE

INTRODUCTION

The western cabbage flea beetle, *Phyllotreta pusilla* Horn (Chrysomelidae: Coleoptera), is a serious pest of spring-planted brassica crops in western North America. Western cabbage flea beetles are small, rapidly moving insects that eat tiny, round "shot-holes" in leaves. They can cause serious damage to young plants, sometimes destroying them in the seedbed. They overwinter as adults and begin feeding early in the spring (Chittenden and Marsh 1920). Insecticides have long been the most widely utilized control method for flea beetles; alternative management tactics such as cultural and biological controls have been less completely investigated. Cultural practices such as plant density intercropping or interplanting, or mixed-plant-culture could better exploited to decrease plant losses caused by flea beetles.

The population dynamics of insect herbivores are strongly affected by the spatial arrangement of their host plant (Pimentel 1961, Root 1973). Plant density, plant diversity and host plant patch size frequently cause the population of herbivorous insects to vary by as much as an order of magnitude (Kareiva 1985). It has also been noted that the population of herbivorous insects on any given plant species depends on the size, number, and spatial organization of host plants (Dethier 1959). Large patch size, for example, enhances pest infestation and colonization (Ralph 1977, Raupp and Denno 1979). Increase in plant density, on the other hand, has often contributed to reduced plant infestation and subsequent damage by pest species (Lugginbill and McNeal 1958, Pimentel 1961, Way and Heathcote 1966, Cromartie 1975, Ehler 1982, Rausher 1983, Way et al. 1983, Segarra-Carmona and Barbosa 1990). Although dense planting might affect population density of most insect pest species, other pest species were found to be unaffected (A'Brook 1968, Jones 1977, Mayse 1978, Stanton 1983).

Plant density, intercropping and/or interplanting have not been investigated previously as part of the cultural control of western cabbage flea beetle infesting brassica crops. Plant population and characteristics of individual plants can influence insect herbivore feeding and distribution, and thus the number of insect herbivores attacking a particular plant is affected by the density of the host plant (Kareiva 1983). Increasing plant density may reduce pest infestation, perhaps because of changes to the microenvironment or in the attractiveness of the crop to a particular pest (Coaker 1987). Dense plantings will lower the contrast of plants against the soil, a cue used by flying insects to find their host plant. For example, cauliflower plants grown at the lowest plant densities received greatest oviposition by the anthomyiid root maggots, *Delia* spp. (Finch and Skinner 1976), and a relatively high plant density (100-140 plants/m^2) of canola grown in the United Kingdom is important for reducing the infestation of the root maggots (Finch 1989). Several studies on brassica pests planted at different densities (Pimentel 1961) and against different backgrounds (Smith 1969, 1976) have shown that growing them silhouetted against bare soil is the best way to attract immigrant aphids. Other studies on groundnuts (A'Brook 1968), beans (Way and Heathcot 1966) and sugarbeet (Heathcot 1970) have also shown levels of aphid infestation and transmission of viruses to be inversely related to plant density.

Interplanting, intercropping, or strip intercropping practices also contribute to population suppression of various insect pests (Laster 1974, Altieri et al. 1977, Altieri and Whitcomb 1979, Powell 1985, Altieri 1993, Pavauk and Barrett 1993). A number of reviews are available that describe the theory and experience of intercropping (Altieri and Whitcomb 1979, Altieri and Letourneau 1982, Andow 1991, Dempster and Coaker 1974). Intercropping or interplanting has been used most commonly in brassica crop plantings (Andow et al. 1986, Kloen and Altieri 1990, O'Donnel and Coaker 1975, Perrin and Phillips 1978, Ryan et al. 1980, Theunissen and den Ouden 1980, Theunissen et al. 1992, Theunissen et al. 1995, Theunissen and Schelling 1978, Tukahirwa and Coaker 1982); however, this practice has also been used in other vegetable plantings including carrots and onions (Uvah and Coaker 1984), field beans (Tingey and Lamont 1988) and leek (Theunissen and Schelling 1993).

It has been suggested that intercropping can be a potential control method to reduce arthropod pest infestation and subsequent damage (Dempster and Coaker 1974, Altieri et al. 1978, Andow 1991). Intercropping is traditionally practiced by subsistence farmers in most developing countries and is largely based on farmers' experience rather than scientific methods (Litsinger and Moody 1976, Okigbo and Greenland 1976, Zethner 1995). A reduction in pest infestation was reported in 50% of cases studied after switching from monocrop to intercrop systems (Andow 1991).

In some circumstances, intercropping or interplanting brassica crops with a susceptible, tolerant, and/or more favorable host plant that can be used as a trap crop may effectively divert the insect attack away from the crop at risk (Hokkanen 1991). The more attractive and preferred host plant is used as a diversionary crop that can be sacrificed after establishment of the main crop. This system can only succeed if the pest species has a narrow host range and that the interplanted crop is attractive to the target pest and tolerant of heavy attack (Coaker 1987).

A large number of studies have emerged in the last couple of decades indicating that interplanting frequently results in reduced pest incidence (Risch et al. 1983). Interplanting influences specialized herbivore densities primarily by altering movement patterns or searching behavior (Kareiva 1983), natural enemy activity, or food resource concentrations (Root 1973, Feeny 1976, Helenius 1990). In Great Britain, for example, Brussels sprouts and sugarbeets had more damaging insects in plots where weeds were removed than in plots where weeds remained (Innis 1997). This was because weed removal deprived insects of alternative food sources that diverted them away from the main crop. Interplanting collards with wild mustard resulted in reduced density of the flea beetle *Phyllotreta cruciferae* Goeze (Altieri and Gliessman 1983). Flea beetle density was reduced on weedy collards compared to those weed-free because the beetles preferred wild mustards to collards. Higher concentrations of the powerful attractant allyl isothiocyanate in mustards were speculated as the basis of this effect.

Specialist herbivores tend to be at higher densities in simple habitats than in diverse habitats (Pimentel 1961, Root 1973, Andow 1983, Risch et al. 1983). When specialized herbivores are presented with random choices of two or more similar host plants, all emitting similar attractive volatile compounds (Finch 1980), their response might be explained not by differences in colonization or movement patterns, but rather by differential feeding preferences resulting in the herbivores concentrating their feeding on one plant species rather than on another (Tahvanainen and Root 1972). For example, in California, interplanting alfalfa in cotton helped in reducing damage to cotton caused by *Lygus* spp. (Stern 1969). Interplanting alfalfa provided a more favorable habitat to the *Lygus* diverting the pest away from the cotton. Interplanting can also shift the attack of insect pest to less valuable crop and thereby reduce the damage to the more valuable main crop.

Altieri and Schmidt (1986) studied the effects of plant assemblages on flea beetles, *P. cruciferae*, by manipulating both host and non-host plant diversity, density, quality and plot size, and also determined some of the mechanisms underlying these effects. These studies have shown that population densities of flea beetles were lower per unit of collard plant in polycultures composed of either non-host plants (field bean, vetch and barley) or of additional host plants (wild mustard) than in collard monocultures. They also showed that significantly fewer flea beetles occurred in collard rows immediately adjacent to wild mustard borders, but their numbers tended to increase with distance from the border. In addition, they proved that spraying collard plants with wild mustard extracts, and especially with allyl isothiocyanate emulsions, is more attractive to flea beetles than collard plants sprayed with water. The authors concluded that these spatial and temporal attractions, which are chemically mediated, may lead to development of effective trap cropping systems for flea beetle control in crucifer crops.

The aim of the present study was to document simultaneously the relationship between host plant density and flea beetle density. Other objectives were to determine if interplanting broccoli with a flea beetle-susceptible, tolerant host (radish) would reduce infestation of seedling broccoli. This would involve use of radish plants as diversionary crop that can be sacrificed after establishment of the main crop. Radish was chosen for this because it is attractive to western cabbage flea beetle but tolerant of its feeding, it establishes readily, and its seed is inexpensive.

METHODS AND MATERIALS

Planting Density Evaluations

Host plant density trials were conducted at the Horticulture Field Research Center in Fort Collins, Colorado. Trials were performed during the summer of 1996, 1997 and 1998 on naturally occurring flea beetle populations. Broccoli, *Brassica oleracea* ssp. *italica* (cv. 'Premium Crop', The Rocky Mountain Seed Co.), was planted in the greenhouse for about 4 weeks prior to field transplantation. After transplanting to the field, broccoli plants were grown under standard husbandry practices. Weeds were controlled by hand weeding when and where necessary. Individual plots consisted of single rows, each 4.5 meters in length in 1996 and 1997 and 3 meters in length in 1998. Experiments were of a randomized complete block design with four different planting densities (5, 10, 20 and 40 cm in row spacing) as treatments in four blocks in 1996 and 1997 and three blocks in 1998. There were 1.5-m gaps separating each block from the others. Insect and plant counts were made by taking 1.5 meter long plots in the center of each plot, and counting all flea beetles on all plants within the 1.5-m plots. Counting of flea beetles was similar to that described in the previous chapter.

In 1996, broccoli seedlings were transplanted on 14 May. Insect and plant counts were made in weekly intervals on 17, 21, and 30 May, 3, 6, 12, 18, and 26 June, and 3 and 12 July. In 1997, seedlings were transplanted on 19 May. Insects and plant counts were made on 2, 6, 12 and 23 June, and 2 July. In 1998, seedlings were transplanted on 18 May. Sampling was done on 27 May, 2, 10, 16, 22 and 30 June, and 8 July.

Interplanting Evaluations

Interplanting trials were conducted at the Horticulture Field Research Center in Fort Collins, Colorado. Trials were performed during the summer of 1997 and 1998 on naturally occurring flea beetle populations. In 1997, Broccoli (cv. 'Premium Crop') seedlings were transplanted on May 21 in single rows (39-cm in-row spacing in 4.5-m long plots). Radish, *Raphanus sativus* L. (cv. 'Sparkler', The Rocky Mountain Seed Co.) seedlings were intertransplanted with the broccoli seedlings on the same day. Plots were either interplanted with radish in 8, 15, or 30-cm in-row spacing or were not planted with radishes as a control. Plots were arranged in a randomized complete block design with 4 treatments and four replications. The number of flea beetles on the broccoli was measured, by whole plant examination of 6 plants/plot, on 2, 6, 12, 16, and 23 July, and 2, 9, and 16 July 1997. Broccoli yield was measured on 13 August by taking the weight of five broccoli heads per plot.

In 1998 interplanting studies, Broccoli (cv. 'Premium Crop') seedlings were transplanted on 18 May in single rows (41-cm in-row spacing in 4.5-m long plots). Daikon radish (cv. 'Chinese Daikon', The Rocky Mountain Seed Co.) seedlings were interplanted within the broccoli seedlings the same day. Plots were either interplanted with radish in 5, 10, or 20-cm in-row spacing or included a no radish control. Plots were arranged in a randomized complete block design with four treatments and four replications. The number of flea beetles on the broccoli was determined by whole plant examination of 5 plants/plot, on 27 May, 3, 10, 16, 22, and 30 June and 8 July. Flea beetles were counted on broccoli plants using the "sneak-up method" described above. Broccoli yield was not measured for the 1998 interplanting study because of heavy false chinch bug, *Nysius raphanus* Howard (Hemiptera: Lygaeidae), infestation of broccoli plants.

In an effort to identify radish cultivars that might work best as a diversionary trap crop, field and laboratory choice trials were conducted in 1997 using 14 different radish cultivars. These included 'Round Black Spanish', 'Champion', 'Chinese Daikon', 'Chinese Rose Winter', 'Crimson Giant', 'Early Scarlet Globe', 'Easter Egg II Blend', 'Sparkler', and 'White Icicle', 'Snow Belle' (The Rocky Mountain Seed Co.), 'French Breakfast', 'Plum Purple' (Lake Valley Seed Inc.), 'Cherry Bomb', 'Salad Rose' (W. Atlee Burpee & Co.). In the field trials, radishes were transplanted on 21 May in single row plots, 4.5 meters long, in 38-cm in-row spacing. Plots were arranged in a randomized complete block design with 14 different treatments and four replications. Insect counts were made by whole plant examination of six plants per plot on 2, 6, 12, 16, and 23 June.

In the laboratory choice trial, tests were conducted using screened cages (35-cm wide by 68-cm high by 61-cm deep) with clear polystyrene tops. Cages were placed under wide-spectrum artificial lighting. Radish plants were grown in flats in the greenhouse, watered as needed, and fertilized. Ten-day seedlings were used for each of the experiments. Before transfer to the laboratory seedlings with the media were transferred to 0.03 liter plastic cups (Prairie Packaging Inc.). Four seedlings of each cultivar were placed randomly inside the cage. About 100 adult flea beetles were introduced into the cage and left to feed for 24 hours. All seedlings were then removed from the cage for feeding evaluation. Insect feeding to seedlings was estimated by counting the feeding holes made by flea beetles. Each test was replicated and repeated four times.

To examine the effects of host plant density and interplanting on the colonization and infestation of western cabbage flea beetle, data were analyzed with two-way ANOVA (SAS institute 1985), testing for effects of plant density and block. Analyses were carried out on the mean number of flea beetles per area and per plant for planting density and per plant for interplanting for each treatment for each block. Comparisons of planting density and interplanting were carried out using Student-Newman-Keuls (SNK) (SAS institute 1985). Statistical analysis of flea beetle densities was carried out both on beetle numbers per plot and number per plant within the plot.

RESULTS AND DISCUSSION

Planting Density Evalauations

In the 1996 trials (Tables 3.1, 3.2), some significant differences existed among treatments (P<0.05) in the number of flea beetles observed on broccoli plants per area (number of flea beetle in all plants within 1.5-m plot in different planting density) and per plant (number of flea beetles observed on individual broccoli plants within 1.5-m plot in different planting density). The number of flea beetles colonizing all broccoli plants in a 1.5-m plot was lower as planting density decreased. For the 30 May, and 3, 6, and 12 June sampling (Table 3.1), the total number of flea beetles colonizing broccoli plants throughout the plots were significantly lower in the 40-cm in-row spacing plant density than in the 5, 10, and 20-cm plant density (F=6.54, P=0.0122; F=7.31, P=0.0087; F=3.97, P=0.0465; F=5.08, P=0.025, respectively). However, the number of flea beetles colonizing individual plants in the 1.5-m plots was significantly higher in decreased plant density plots (Table 3.2); most of the sampling dates showed a significant increase (P<0.05) in the number of adult flea beetles colonizing individual plants as the broccoli plants were more widely spaced. In the 3, 6, 12, 18, 26 June, and 3 and 12 July sampling dates, the number of flea beetles colonizing individual broccoli plants with 40-cm in-row spacing was significantly higher among treatments (F=5.23, P=0.0231; F=5.42, P=0.0210; F=10.69, P=0.0025; F=46.99, P=0.0001; F=18.63, P=0.0003; F=15.45, 0.0007; F=4.70, P=0.0306, respectively).

Table 3.1. Mean number of western cabbage flea beetles per plot observed on broccoli (cv. 'Premium Crop') planted at different densities, Colorado State University Horticulture Field Research Center, Fort Collins, CO, 1996

Planting Density	No. of Plants / 1.5-m plot	Mean number of flea beetles / plot[a]									
		17-May	21-May	30-May	3-Jun	6-Jun	12-Jun	18-Jun	26-Jun	3-Jul	12-Jul
5 cm in-row spacing	30 plants	8.25 a	3.50 a	29.50 a	60.50 a	37.00 a	64.50 a	89.00 a	20.00 a	15.75 a	15.50 a
10 cm in-row spacing	15 plants	6.75 a	1.75 a	35.00 a	49.00 a	32.00 ab	60.50 a	86.25 a	28.75 a	19.25 a	14.50 a
20 cm in-row spacing	8 plants	6.75 a	1.25 a	18.00 a	43.00 a	27.50 ab	56.50 a	88.00 a	19.25 a	14.75 a	8.75 a
40 cm in-row spacing	4 plants	5.00 a	2.00 a	11.25 b	19.00 b	15.25 b	38.75 b	56.25 a	30.25 a	10.50 a	6.50 a

[a]Means within a column followed by the same letter are not significantly different (P=0.05) by SNK test. Means are based on number of flea beetles counted on all broccoli plants on 1.5-m plots for 4 replications.

Table 3.2. Mean number of western cabbage flea beetles per plant observed on broccoli (cv. 'Premium Crop') planted at different densities, Colorado State University Horticulture Field Research Center, Fort Collins, CO, 1996.

Planting Density	No. of Plants/1.5-m plot	Mean number of flea beetles / plant[a]									
		17-May	21-May	30-May	3-Jun	6-Jun	12-Jun	18-Jun	26-Jun	3-Jul	12-Jul
5 cm in-row spacing	30 plants	0.28 a	0.12 a	0.98 a	2.02 b	1.23 b	2.15 c	2.97 d	0.67 c	0.53 c	0.52 b
10 cm in-row spacing	15 plants	0.45 a	0.12 a	2.33 a	3.27 ab	2.13 ab	4.03 bc	5.75 c	1.92 bc	1.28 b	0.97 ab
20 cm in-row spacing	8 plants	0.84 a	0.16 a	2.25 a	5.38 a	3.41 a	7.06 ab	11.00 b	2.41 b	1.84 b	1.09 ab
40 cm in-row spacing	4 plants	1.25 a	0.50 a	2.81 a	4.75 a	3.81 a	9.69 a	14.06 a	7.56 a	2.63 a	1.63 ab

[a]Means within a column followed by the same letter are not significantly different (P=0.05) by SNK test. Means are based on number of flea beetles per plant for 4 replications.

In the 1997 plant density studies (Tables 3.3, 3.4), the number of flea beetles colonizing broccoli plants in a 1.5-m area and the number of flea beetles colonizing individual plants within that area showed a similar trend, except on the 2 July sampling date. The number of flea beetles colonizing broccoli plants in a 1.5-m plot was significantly different among treatments in all sampling dates (Table 3.3). In the 2, 6, 12, 16, and 23 June sampling dates, the number of flea beetles was significantly lower in the 40-cm in-row spacing plant density than in the 5 and 10-cm plant densities (F=25.85, P=0.0001; F=9.75, P=0.0016; F=14.55, 0.0008; F=8.65, P=0.0051; F=7.73, P=0.0073, respectively). In the 2 July sampling date, the number of flea beetles colonizing broccoli plants in a 1.5-m plot was significantly higher for the 40-cm plant density than for the 2-cm plant density (F=4.15, P=0.0281). The number of flea beetles colonizing individual broccoli plants within the 1.5-m plot, however, was significantly higher as the broccoli plants were separated further apart (Table 3.4). In the 2, 12, 16, and 23 June, and 2 July sampling dates, the number of flea beetles colonizing individual plants in 1.5-m was significantly higher in the 40-cm planting density than in the 5-cm planting density (F=8.89, P=0.0047; F=12.69, P=0.0014; F=20.01, P=0.0003; F=16.55, P=0.0005; F=22.84, P=0.0002, respectively).

Table 3.3. Mean number of western cabbage flea beetles per plot observed on broccoli (cv. 'Premium Crop') planted at different densities, Colorado State University Horticulture Field Research Center, Fort Collins, CO, 1997.

Planting Density	No. of Plants / 1.5-m plot	Mean number of flea beetles / plot[a]					
		2-Jun	6-Jun	12-Jun	16-Jun	23-Jun	2-Jul
5 cm in-row spacing	30 plants	66.25 a	45.50 a	94.25 a	130.50 a	83.50 a	11.75 b
10 cm in-row spacing	15 plants	42.50 b	45.00 a	80.75 a	148.75 a	96.25 a	30.25 a
20 cm in-row spacing	8 plants	38.25 b	23.25 b	49.75 b	84.50 b	53.50 b	21.50 a
40 cm in-row spacing	4 plants	21.50 c	11.50 c	37.75 b	72.75 b	46.50 b	33.25 a

[a]Means within a column followed by the same letter are not significantly different (*P*=0.05) by SNK test. Means are based on number of flea beetles counted on all broccoli plants in 1.5-m plots for 4 replications.

Table 3.4. Mean number of western cabbage flea beetles per plant observed on broccoli (cv. 'Premium Crop') planted at different densities, Colorado State University Horticulture Field Research Center, Fort Collins, CO, 1997.

Planting Density	No. of Plants / 1.5-m plot	Mean number of flea beetles / plant[a]					
		2-Jun	6-Jun	12-Jun	16-Jun	23-Jun	2-Jul
5 cm in-row spacing	30 plants	2.21 b	1.52 a	3.14 c	4.35 c	2.78 c	0.39 c
10 cm in-row spacing	15 plants	2.83 b	3.00 a	5.38 bc	9.92 b	6.42 b	2.02 b
20 cm in-row spacing	8 plants	4.78 a	2.91 a	6.22 b	10.56 b	6.69 b	2.69 b
40 cm in-row spacing	4 plants	5.38 a	2.88 a	9.44 a	18.19 a	11.63 a	8.31 a

[a]Means within a column followed by the same letter are not significantly different (*P*=0.05) by SNK test. Means are based on number of flea beetles per plant for 4 replications.

In the 1998 planting density studies (Tables 3.5, 3.6), the number of flea beetles colonizing broccoli plants per area and per plant had a similar trend as in the 1996 and 1997 trials. The number of flea beetles colonizing broccoli plants in 1.5-m plots was significantly different among treatments (Table 3.5). In the 22, 27, and 30 June, the number of flea beetles was significantly lower on 40-cm in-row plant density than in the 5-cm plant density (F=7.74, P=0.0073; F=17.26, P=0.0004; F=4.21, P=0.0406, respectively). The number of flea beetles colonizing individual broccoli plants in a 1.5-m plot, however, was significantly higher as the plant density decreased (Table 3.6). In the 10, 16, 22, and 30 June, and 8 July sampling dates, the number of flea beetles colonizing individual plants within a 1.5-m plot was significantly higher in the 40-cm in-row spacing plant density than in the 5-cm plant density (F=8.412, F=0.0056; F=27.12, P=0.0001; F=44.53, P=0.0001; F=14.02, P=0.0010, respectively).

Table 3.5. Mean number of western cabbage flea beetles per plot observed on broccoli (cv. 'Premium Crop') planted at different densities, Colorado State University Horticulture Field Research Center, Fort Collins, CO, 1998.

Planting Density	No. of Plants / 1.5-m plot	Mean number of flea beetles / plot[a]						
		2-Jun	10-Jun	16-Jun	22-Jun	27-Jun	30-Jun	8-Jul
5 cm in-row spacing	30 plants	3.50 a	34.25 a	27.00 a	26.25 b	42.50 ab	12.50 b	29.50 a
10 cm in-row spacing	16 plants	3.50 a	44.50 a	30.00 a	19.75 b	48.00 a	23.75 ab	40.25 a
20 cm in-row spacing	8 plants	2.25 a	44.00 a	44.25 a	44.75 a	33.75 b	27.25 ab	43.50 a
40 cm in-row spacing	4 plants	4.00 a	26.25 a	27.75 a	29.50 a	16.75 c	32.25 a	35.00 a

[a]Means within a column followed by the same letter are not significantly different (P=0.05) by SNK test. Means are based on number of flea beetles counted on all broccoli plants on 1.5-m plots for 4 replications.

Table 3.6. Mean number of western cabbage flea beetles per plant observed on broccoli (cv. 'Premium Crop') planted at different densities, Colorado State University Horticulture Field Research Center, Fort Collins, CO, 1998.

Planting Density	No. of Plants / 1.5-m plot	Mean number of flea beetles / plant[a]						
		2-Jun	10-Jun	16-Jun	22-Jun	27-Jun	30-Jun	8-Jul
5 cm in-row spacing	30 plants	0.12 a	1.14 c	0.90 b	0.88 c	1.42 a	0.42 b	0.98 c
10 cm in-row spacing	16 plants	0.22 a	2.78 bc	1.88 b	1.23 c	3.00 a	1.49 b	2.52 bc
20 cm in-row spacing	8 plants	0.28 a	5.50 ab	5.53 a	5.59 b	4.22 a	3.41 b	5.44 ab
40 cm in-row spacing	4 plants	1.00 a	6.56 a	6.94 a	7.38 a	4.19 a	8.06 a	8.75 a

[a]Means within a column followed by the same letter are not significantly different (*P*=0.05) by SNK test. Means are based on number of flea beetles per plant for 4 replications.

Interplanting Evaluations

In interplanting studies, the greatest flea beetles densities were found on broccoli in plots with no radishes. In the 1997 interplanting study (Table 3.7), there were significant differences on the 12 June and 9 July sampling dates (F=3.86, P=0.0500; F=4.02, P=0.0455, respectively). Broccoli plants interplanted with radishes in 15-cm in-row spacing in 12 June and in 30-cm in 9 July had lower flea beetle infestation than the control. Although there were differences in flea beetle densities colonizing broccoli plants among treatments, no significant differences were obtained in broccoli yield (F=1.49, P=0.2827) (Table 3.8). In the 1998 interplanting study (Table 3.9), the number of flea beetles colonizing broccoli plants was significantly different among treatments. Broccoli plants interplanted with radishes in 5-cm in-row spacing in 10 June had a significantly lower number of flea beetles than the control (F=4.83, P=0.0486). Also, a significantly lower number of flea beetles than the control was observed in the 5 and 10-cm spacing for the 22 and 30 June and 8 July sampling dates (F=10.24, P=0.0089; F=10.83, P=0.0078; F=9.06, P=0.0120, respectively).

Field and laboratory evaluations of radish cultivars as diversionary crops to attract flea beetles away from broccoli plants gave analogous results. In the field evaluations (Table 3.10) there were significant differences in the number of flea beetles colonizing radishes in all sampling dates (F=0.05, P=0.0035; F=3.31, P=0.0019; F=2.53, P=0.0125; F=5.42, P=0.0001; F=6.45, P=0.0001, respectively). Chinese Daikon and Round Black Spanish had the highest flea beetle infestation among others in the 6, 16 and 23 June. Chinese Daikon have also received significantly higher feeding holes among others in the

26 and 27 June laboratory choice tests (Table 3.11) (F=2.18, P=0.0352; F=3.70, P=0.0011).

Table 3.7. Mean number of western cabbage flea beetles per plant observed on broccoli plants (cv. 'Premium Crop') interplanted with radishes (cv. 'Sparkler') planted at different densities, Colorado State University Horticulture Field Research Center, Fort Collins, CO, 1997.

Radish Density	Mean number of flea beetles / plant[a]							
	2-Jun	6-Jun	12-Jun	16-Jun	23-Jun	2-Jul	9-Jul	16-Jul
Control (No Radishes)	3.30 a	3.30 a	6.05 a	9.70 a	10.19 a	0.70 a	10.35 a	2.60 a
8 cm in-row spacing	3.15 a	3.05 a	4.85 ab	6.75 a	9.69 a	1.45 a	7.25 ab	3.00 a
15 cm in-row spacing	3.95 a	2.20 a	3.80 b	5.80 a	8.94 a	0.95 a	9.70 ab	3.50 a
30 cm in-row spacing	3.35 a	2.15 a	5.65 ab	8.70 a	11.75 a	1.00 a	6.45 b	3.30 a

[a]Means within a column followed by the same letter are not significantly different (P=0.05) by SNK test. Means are based on number of flea beetles per plant for 4 replications.

Table 3.8. Mean head weight of broccoli (cv. 'Premium Crop') per plant harvested from plants interplanted with radishes (cv. 'Sparkler') at different densities, Colorado State University Horticulture Field Research Center, Fort Collins, CO, 1997.

Radish Density	Broccoli Yield (Grams) / Plant[a]
Control (No Radishes)	311.74 a
8 cm in-row spacing	222.81 a
15 cm in-row spacing	326.62 a
30 cm in-row spacing	308.41 a

[a]Means within a column followed by the same letter are not significantly different (P=0.05) by SNK test. Means are based on broccoli head weight per plant for 4 replications.

Table 3.9. Mean number of western cabbage flea beetles per plant observed on broccoli plants (cv. 'Premium Crop') interplanted with radishes (cv. 'Chinese Daikon') planted at different densities, Colorado State University Horticulture Field Research Center, Fort Collins, CO, 1998.

Planting Density	Mean number of flea beetles / plant[a]						
	27-May	3-Jun	10-Jun	16-Jun	22-Jun	30-Jun	8-Jul
Control (No Radishes)	4.33 a	0.20 a	7.00 a	5.00 a	5.27 a	9.00 a	24.07 a
5 cm in-row spacing	2.47 a	0.20 a	2.33 b	2.13 a	1.00 b	2.67 b	7.73 b
10 cm in-row spacing	2.80 a	0.13 a	3.73 ab	2.87 ab	1.00 b	3.60 b	9.33 b
20 cm in-row spacing	3.80 a	0.13 a	5.20 ab	3.93 ab	3.20 ab	6.27 ab	16.67 ab

[a]Means within a column followed by the same letter are not significantly different (P=0.05) by SNK test. Means are based on number of flea beetles per plant for 4 replications.

Table 3.10. Mean number of western cabbage flea beetles per plant observed on different radish cultivars, Colorado State University Horticulture Field Research Center, Fort Collins, CO, 1997.

Radish Cultivar	Mean number of flea beetles / plant[a]				
	2-Jun	6-Jun	12-Jun	16-Jun	23-Jun
Round Black Spanish	8.56 ab	7.88 a	17.06 a	20.88 a	28.25 a
Champion	5.94 b	4.81 ab	6.56 bc	7.44 bc	7.94 cd
Cherry Bomb	5.19 b	3.63 b	5.88 c	5.00 c	5.25 d
Chinese Daikon	12.06 a	7.81 a	16.38 ab	21.63 a	27.81 a
Chinese Rose Winter	5.75 b	5.31 ab	13.13 abc	12.63 abc	17.13 abcd
Crimson Giant	6.06 b	5.63 ab	11.63 abc	9.88 bc	16.38 abcd
Early Scarlet Globe	5.94 b	4.63 ab	10.50 abc	8.25 bc	12.94 bcd
Easter Egg II Blend	6.94 b	5.44 ab	10.19 abc	5.50 c	12.13 bcd
French Breakfast	5.44 b	3.06 b	8.19 abc	7.50 bc	9.25 cd
Plum Purple	7.88 ab	5.94 ab	11.81 abc	9.31 bc	8.56 cd
Salad Rose	7.88 ab	6.06 ab	12.69 abc	17.25 ab	20.25 abc
Snow Belle	6.81 b	3.88 b	8.50 abc	7.88 bc	8.75 cd
Sparkler	5.81 b	4.50 ab	9.13 abc	7.69 bc	10.81 cd
White Icicle	6.75 b	5.75 ab	9.31 abc	14.13 abc	24.13 ab

[a]Means within a column followed by the same letter are not significantly different (P=0.05) by SNK test. Means are based on the number of flea beetles per plants for 4 replications.

Table 3.11. Mean number of flea beetle feeding holes per plant on different radish cultivars, laboratory study, 1997.

Radish Cultivar	No. of Feeding Holes / Plant[a]			
	24-Jun	25-Jun	26-Jun	27-Jun
Round Black Spanish	8.00 a	20.00 a	22.25 ab	5.75 bc
Champion	28.25 a	21.25 a	22.25 ab	25.75 ab
Cherry Bomb	21.75 a	20.25 a	32.50 ab	38.50 ab
Chinese Daikon	16.25 a	26.50 a	47.50 a	60.75 a
Chinese Rose Winter	28.00 a	2.25 a	.	.
Crimson Giant	13.00 a	15.50 a	10.50 b	4.25 c
Early Scarlet Globe	20.00 a	23.00 a	22.25 ab	43.25 a
Easter Egg II Blend	16.00 a	6.25 a	16.00 b	18.50 ab
French Breakfast	17.25 a	4.25 a	19.75 ab	14.25 abc
Plum Purple	25.00 a	17.25 a	18.75 ab	17.00 ab
Salad Rose	17.00 a	14.50 a	17.75 ab	25.75 ab
Snow Belle	23.00 a	31.00 a	20.50 ab	19.50 ab
Sparkler	10.75 a	12.75 a	19.75 ab	42.75 a
White Icicle	18.50 a	19.50 a	11.25 b	26.50 ab

[a]Means within a column followed by the same letter are not significantly different (P=0.05) by SNK test. Means are based on 4 plants per cage for 4 replications.

The above results showed that plant density affects population density of western cabbage flea beetle. Western cabbage flea beetles responded to changes in plant density similarly to other phytophagous insects. Many studies have indicated that populations of specialist herbivores decrease in individual plants as the host plants in an area increase in density (Pimentel 1961, Cort 1982, Delobel 1982, Rausher 1983, Horton and Capinera 1987). The present study demonstrated that increasing plant density results in a considerable decrease in flea beetle population infesting individual broccoli plants and an increase in number of flea beetles in an area with increased plant density. This study may not entirely conflict with previous studies because, given a certain pest population, an increase in plant density (more plants per unit area) can increase the number of insects infesting all plants in a unit area but decrease the number of insects infesting individual plants within that area.

In general, western cabbage flea beetles tend to be lowest in areas of reduced planting densities and highest on individual plants within that area. Several researchers reported similar findings with other insects (A'Brook 1968, Farrell 1976, Coaker 1987) with some exceptions (Mayse 1978, Troxclair and Boethel 1984). Some of the explanations for lower insect populations in dense plantings are that excess vegetation deters oviposition (Delobel 1981) and that dense plantings alter the microenvironment favored by the pest (Coaker 1987). Some flying insects use the spacing contrasts between bare ground and vegetative cover as cues for landing responses, thus the increases in plant density can deter landing and cause overall reduction in pest infestations and populations (A'Brook 1968). Finch and Skinner (1976) studied the effect of cauliflower plant density on populations of

D. radicum and reported that oviposition per individual plant was approximately three times greater at the lowest than at the highest plant densities evaluated. Increases in plant density may result in analogous increases in the overall populations of pest species. This, however, may compensate for pest-induced yield losses. Finch and Skinner (1976) reported that even though increasing the plant density considerably increased the absolute population of *D. radicum*, broccoli yield was unaffected.

Western cabbage flea beetle populations on individual broccoli plants are reduced as the plant densities increase. This may be due to changes in total fitness and vegetative size of broccoli plants planted at different densities which may affect beetle preference. Dosdall et al. (1995) reported that changes in basal stem diameter of canola plants at increased plant density contributed in reduced infestation by *Delia* spp.; canola plants grown at lower densities developed larger basal stems than plants grown at higher densities. This led to a higher oviposition rate by *Delia* spp. resulting in greater infestation at lower plant densities. Similarly, Lunginbill and MacNeal (1958) reported planting wheat at high densities decreased stem diameter, stem moisture content, and plant height, and, thus, decreased damage by the wheat stem sawfly, *Cephus cinctus* Norton. Since the wheat stem sawfly prefers larger, more succulent plants for oviposition, damage to wheat decreased as plant density increased.

The present study also determined that interplanting of a more preferred host plant (radish) within a broccoli crop can be an effective mechanism to reduce the western cabbage flea beetle infestation and subsequent damage. The highest density of flea beetles was found in plots with no radishes interplanted among broccoli. Although radish plants can support large numbers of flea beetles, it is often difficult to demonstrate that broccoli plants have been protected. These results showed that radish (e.g., 'Chinese Daikon') is a preferred host over other commercial brassica crops; radish plants can reduce infestation levels in the adjacent broccoli plants. Thus, radish has potential as a pest management tool in brassica crop plantings.

Interplanting broccoli with radish did not significantly increase head weight and the subsequent yield of broccoli plants compared to non-interplanted broccoli. Moreover, lowest yield was observed on plots with the highest radish density (8-cm in-row spacing). This may be attributed to the fact that the availability of high density of the more preferred host plant within broccoli plants attracted more flea beetles and caused more damage compared to control and the other interplanting treatments. Competition for water, nutrients or light can influence growth and yield more than the pests (Martin et al. 1989). Therefore, another possible explanation is that higher radish density competes for water, nutrients, or light influencing the growth and yield of broccoli plants. This might be eliminated if radishes were rogued after broccoli plants were well established and after the period of flea beetle susceptibility.

In general terms, the above findings for western cabbage flea beetle management imply that plant density and interplanting can be a potentially viable cultural control and possible alternative to insecticides. However, several questions need to be addressed before making recommendations to growers. Increasing plant density (decreasing spacing) involves increase in seeding/transplanting rate per acre. The economic feasibility of increasing seeding (and/or planting rate) and interplanting to reduce infestation and colonization of the western cabbage flea beetle will depend on several factors. Such factors involve the cost of the seeds for planting, the market value of the main crop, planting cost, and the extent of western cabbage flea beetle infestation. In conjunction with the above findings, economic feasibility and grower acceptance are also required. Grower acceptance will strongly depend on degree of capitalization, pesticide use restrictions, and on value of noninsecticide-treated produce.

Furthermore, implementation of interplanting may not be always beneficial as some interplanted crops may serve as a refuge for the insect to get food, shelter and multiply before severely attacking the main crop. Moreover, interplanting of a more preferred host plant would sometimes attract more flea beetles to the main crop. Plant density and/or interplanting as a cultural practice to control flea beetles in brassica crops might be a most effective control when combined with other pest management tactics, including insecticide applications, host plant resistance, and mass trapping.

REFERENCES CITED

A'Brook, J. 1968. The effect of plant spacing on the numbers of aphids trapped over the groundnut crop. Ann. Appl. Biol. 61: 289-294.

Altieri, M. A. 1993. Crop protection strategy for subsistence farmers. Westview Studies in Insect Biology. Boulder, Westview Press. 197 pp.

Altieri, M. A., and S. R. Gliessman. 1983. Effects of plant diversity on the density herbivory of the flea beetle, *Phyllotreta cruciferae* Goeze, in California collard (*Brassica oleracea*) cropping systems. Crop Protection. 2: 497-501.

Altieri, M. A. and D. K. Letourneau. 1982. Vegetation management and biological control in agroecosystem. Crop Protection 1: 405-430.

Altieri, M. A. and L. L. Shmidt. 1986. Population trends and feeding preferences of flea beetles (*Phyllotreta cruciferae* Goeze) in collard-wild mustard mixtures. Crop Protection 5: 170-175.

Altieri, M. A. and W. H. Whitcomb. 1979. The potential use of weeds in the manipulation of beneficial insects. Hort. Sci. 8: 12-18.

Altieri M. A., A. van Schoonhoven and J. D. Doll. 1977. The ecological role of weeds in insect pest management system: A review illustrated by bean (*Phaseolus vulgaris*) cropping systems. PANS. 23: 195-205.

Altieri M. A., A. van Schoonhoven and J. D. Doll. 1978. A review of insect prevalence in maize (*Zea mays* L.) and bean (*Phaseolus vulgaris* L.) polycultural systems. Field Crops Res. 1:33-49.

Andow, D. A. 1983. The extend of monoculture and its effects on insect populations with particular preference to wheat and cotton. Agric. Ecosys. Environ. 9: 25-35.

Andow D. A. 1991. Vegetational diversity and arthropod population response. Ann. Rev. Entomol. 36: 561-586.

Andow, D. A., A. G. Nicholson, H. C. Wien and H. R. Wilson. 1986. Insect population on cabbage grown with living mulches. Environ. Entomol. 15: 293-299.

Chittenden, F. H. and H. O. Marsh. 1920. The western cabbage flea beetle. USDA, Bulletin No. 902. 21 pp. Washington D.C.

Coaker, T. H. 1987. Cultural methods: the crop. Pp.69-88. *In* A. J. Burn, T. H. Coaker and P. C. Jepson (eds.), Integrated Pest Management. Academic Press, London, UK.

Cort, R. P. 1982. Insect communities on potatoes: the effect of plant community structure. Ph.D. Dissertation, State University of New York, Stony Brook.

Cromartie, W. J. 1975. The effect of stand size and vegetational background on the colonizations of cruciferous plants by herbivorous insects. J. Appl. Ecol. 12: 517-533.

Delobel, A. G. L. 1981. Effects of sorghum density on oviposition and survival of the sorghum shoot fly, *Atherigona soccata*. Entomol. Exp. Appl. 31: 170-174.

Dempster, J. P. and T. H. Coaker. 1974. Diversification of crop ecosystem as a means of controlling pests. Pp. 106-114. *In* D. P. Jones and M. E. Solomon (eds.), Biology in Pest and Disease Control. Blackwell, Oxford.

Dethier, V. G. 1959. Egg-laying habitats of Lepidoptera in relation to available food. Can. Entomol. 91: 554-561.

Dosdall, L. M., M. J. Herbut, N. T. Cowle, and T. M. Micklich. 1995. The effect of seeding date and plant density on infestation of root maggot, *Delia* spp. (Diptera: Anthomyiidae), in canola. Can. J. Plant Sci. 76: 169-177.

Ehler, L. E. 1982. Observation on *Trialeuroides pakardi* (Morrill) in a community garden (Homoptera: Aleyrodidae). Pan-Pac. Entomol. 58: 291-295.

Farrell, J. A. 1976. Effects of groundnut crop density on the population dynamics of *Aphis craccivora* Koch (Hemiptera, Aphididae) in Malawi. Bull. Entomol. Res. 66: 317-329.

Feeny, P. 1976. Plant apparency and chemical defense. Pp. 1-40. *In* JW Wallace and RL Mansell (eds.), Recent Advances in Phytochemistry. Biochemical Interaction Between Plants and Insects, vol. 10. New York, Plenum Press.

Finch, S. 1980. Chemical attraction of plant-feeding insects to plants. Appl. Biol. 5: 67-143.

Finch, S. 1989. Ecological considerations in the management of *Delia* pest species in vegetable crops. Ann. Rev. Entomol. 34: 117-137.

Finch, S. and G. Skinner. 1976. The effect of plant density on populations of the cabbage root fly (*Erioischia brassica* (Bch.)) and the cabbage stem weevil (*Ceutorhynchus quadridens* (Panz.)) on cauliflower. Bull. Entomol. Res. 66: 113-123.

Helenius, J. 1990. Incidence of specialist natural enemies of *Rhopalasiphum padi* (L.) (Homoptera, Aphididae) on oats in monocrops and mixed intercrops with faba bean. J. Appl. Entomol. 109: 136-143.

Heathcot, G. D. 1970. Effects of plant spacing and time of sowing of sugar beat on aphid infestation and spread of virus yellows. Pl. Path. 19: 32-39.

Hokkanen, H. M. 1991. Trap cropping in pest management. Ann. Rev. Entomol. 36: 119-138.

Horton, D. R. and J. L. Capinera 1987. Effects of plant diversity, host density, and host size on population ecology of the Colorado potato beetle (Coleoptera: Chrysomelidae). Environ. Entomol. 16: 1019-1026.

Innis, D. Q. 1997. Intercropping and the Scientific Basis of Traditional Agriculture. International Technology Publications Ltd. London, UK. 170 pp.

Jones, R. E. 1977. Movement patterns and egg distribution in cabbage butterflies. J. Anim. Ecol. 46: 195-212.

Kareiva, P. 1983. Influence of vegetation texture on herbivore populations: resource concentration and herbivore movement, pp. 259-289. *In* R. Denno (ed.) Variable plants and herbivores in natural and managed systems. New York: Academic Press.

Kareiva, P. 1985. Finding and losing host plants by *Phyllotreta*: patch size and surrounding habitat. Ecology 66: 1809-1816.

Kloen, H. and M. A. Altieri. 1990. Effect of mustard (*Brassica hirta*) as a non-crop plant on competition and insect pests in broccoli (*Brassica oleracea*). Crop Protection 9: 90-96.

Laster, L. M. 1974. Increasing natural enemies resources through crop rotation and strip cropping. Pp. 137-143. *In* F. C. Maxwell and F. A. Harris (eds.), Proceeding of the Summer Institute on Biological Control of Plant Insects and Diseases. Univ. Press of Mississippi, Jackson. 647 pp.

Litsinger, J. A. and K. Moody. 1976. Integrated pest management in multiple cropping systems. Pp. 293-317. *In* R. I. Papendick, P. A. Sanchez and G. B. Triplett (eds.), Multiple Cropping. American Society and Agronomy, Madison, WI.

Lunginbill, P. and F. H. McNeal. 1958. Influence of seeding density and row spacing on the resistance of spring wheat to the wheat stem sawfly. J. Econ. Entomol. 51: 808-809.

Martin, R. C., J. T. Arnason, J. D. H. Lambert, P. Isabelle, H. D. Voldeng, and D. L. Smith. 1989. Reduction of European corn borer by intercropping corn with soybean. J. Econ. Entomol. 82: 1455-1459.

Mayse, M. A. 1978. Effects of spacing between rows on soybean arthropod populations. J. Appl. Ecol. 15: 439-450.

O'Donnel, M. S. and T. H. Coaker. 1975. Potential of intercrop diversity for the control of brassica pests. Proceedings 8th British Insecticide and Fungicide Conference 1975: 101-105.

Okigbo, B. N. and G. J. Greenland. 1976. Integrated pest management in multiple cropping systems. Pp. 63-101. *In* R. I. Papendick, P. A. Sanchez and G. B. Triplett (eds.), Multiple Cropping. American Society and Agronomy, Madison, WI.

Pavauk, D. M. and G. W. Barrett. 1993. Influence of successional and grassy corridor on parasitism of *Plathypena scabra* (F.) (Lepidoptera: Noctuidae) larvae in soybean agroecosystems. Environ. Entomol. 21: 1371-1376.

Perrin, R. M. and M. L. Phillips. 1978. Some effects of mixed cropping on the population dynamics of insect pests. Entomol. Exp. Appl. 24: 585-593.

Pimentel, D. 1961. The influence of plant spatial patterns on insect populations. Ann. Entomol. Soc. Amer. 54: 61-69.

Powell, W. 1985. Enhancing parasitoid activity in crops. Pp. 319-340. *In* J. Waage and D. Greathead (eds.), Insect Parasitoids: 13th Symposium of the Royal Entomological Society of London. Academic Press, London. 389 pp.

Ralph, C. P. 1977. Effect of host plant density on populations of specialized seed-seeking bug, *Oncopletus fasciatus*. Ecology 58: 799-809.

Raupp, M. J., and R. F. Denno. 1979. The influence of patch size on a guild of sap-feeding insects that inhibit the salt marsh grass *Spartina patens*. Environ. Entomol. 8: 412-417.

Rausher, M. D. 1983. Alteration of oviposition behavior by *Battus philenor* butterflies in response to variation in host plant density. Ecology 64: 1028-1034.

Risch, S. J., D. Andow, and M. A. Altieri. 1983. Agroecosystem diversity and pest control: Data, tentative conclusions and new research directions. Environ. Entomol. 12: 625-629.

Root, R. B. 1973. Organization of a plant-arthropod association in simple and diverse habitats: the fauna of collards (*Brassica oleracea*). Ecol. Monogr. 43: 95-124.

Ryan, J. M. P. Ryan and P. McNaedhe. 1980. The effect of interrow plant cover on populations of the cabbage root fly, *Delia brassicae* (Wiedemann). J. Appl. Ecol. 17: 31-40.

SAS Institute. 1985. SAS user's guide: Statistics, 5th ed. SAS Institute, Cary, NC.

Segarra-Carmona, A. and F. Barbosa. 1990. Influence of patch plant density on herbivory levels by *Etiella zinckenella* (Lepidoptera: Pyralidae) on *Glycine max* and *Crotalaria pallida*. Environ. Entomol. 19: 640-647.

Smith, J. G. 1969. Some effects of crop background on populations of aphids and their natural enemies on Brussels sprouts. Ann. Appl. Biol. 63: 326-330.

Smith, J. G. 1976. Influence of crop background on aphids and other phytophagous insects on Brussels sprouts. Ann. Appl. Biol. 83: 1-13.

Stanton, M. L. 1983. Spatial patterns in the plant community and their effect upon insect search, pp. 125-155. *In* S. Ahmad (ed.), Herbivorous insects: host-seeking behavior and mechanisms. Academic Press, New York, New York.

Stern, V. M. 1969. Interplanting alfalfa in cotton to control *Lygus* bugs and other insect pests. Proc. Tall Timbers Conf. on Ecol. Animal Control by Habitat Management 1: 55-69.

Tahvanainen, J. O., and R. B. Root. 1972. The influence of vegetational diversity on the population ecology of a specialized herbivore, *Phyllotreta cruciferae* (Coleoptera: Chrysomelidae). Oecologia. 10: 321-342.

Theunissen, J. and H. den Ouden. 1980. Effects of intercropping with *Spergula arvensis* on pests in Brussels sprouts. Entomol Exp. Appl. 27: 260-268.

Theunissen, J., C. J. H Booij, G. Schelling and J. Noorlander. 1992. Intercropping white cabbage with clover. *In* Working Group 'Integrated control in field vegetable crops'. IOBC/WPRS Bull. 1992/XV/4: 104-114.

Theunissen, J., C. J. H. Booij, G. Schelling and L. A. P. Lotz. 1995. Effects of intercropping white cabbage with clovers on pest infestation and yield. Entomol. Exp. Appl. 74: 7-16.

Theunissen, J. and G. Schelling. 1978. Cabbage clover intercropping: oviposition of *Delia radicum*. Proceeding of the Section Experimental and Applied Entomology of the Netherlands Entomological Society 3: 191-196.

Theunissen, J. and G. Schelling. 1993. Suppression of *Thrips tabaci* populations in intercropped leek. Mededelingen van de Faculteit Landbpuwwetenschappen Rijksuniversiteit (Gen) 58/2a: 383-390.

Tingey, W. M. and W. J. Lamont. 1988. Insect abundance in field beans altered by intercropping. Bull. Entomol. Res. 78: 527-535.

Tukahirwa E. M. and T. H. Coaker. 1982. Effect of mixed cropping on some insect pests of brassicas; reduced *Brvicoryne brassicae* infestations and influences on epigeal predators and the disturbance of oviposition behaviour in *Delia brassicae*. Entomol. Exp. Appl. 32: 129-140.

Troxclair, N. N. and D. J. Boethel. 1984. Influence of tillage practices and row spacing on soybean insect populations in Louisiana. J. Econ. Entomol. 77: 1571-1579.

Uvah, I. I. I. and T. H. Coaker. 1984. Effect of mixed cropping on some pests of carrots and onions. Entomol. Exp. Appl. 36: 159-167.

Way, M. J. and G. D. Heathcot. 1966. Interactions of crop density of field beans , abundance of *Aphis fabae* Scop. Virus incidence and aphid control by chemicals. Ann. Appl. Biol. 57: 400-423.

Way, M. O., A. A. Grigarick and S. E. Mahr. 1983. Effects of rice plant density, rice water weevil (Coleoptera: Curculionidae) damage to rice, and aquatic weeds on aster leafhopper (Homoptera: Cicadellidae) density. Environ. Entomol. 12: 949-952.

Zethner, O. 1995. Practice of integrated pest management in tropical and sub-tropical Africa: an overview of two decades (1979-1990). Pp. 1-67. *In* AN Mengech, K Saxena and HNB Gopalan (eds.), Integrated Pest Management in the Tropics. John Wiley, New York.

CHAPTER IV

ATTRACTIVENESS OF

COLOR TRAPS AND ALLYL ISOTHIOCYANATE

TO WESTERN CABBAGE FLEA BEETLE ADULTS

INTRODUCTION

The western cabbage flea beetle, *Phyllotreta pusilla* Horn (Chrysomelidae: Coleoptera), is a serious pest of cabbage and other brassica crops. The adult beetles are most noticeable in the early spring when they leave overwintering sites to feed on seedlings of wild and then cultivated brassica crops (Chittenden and Marsh 1920). Larval feeding damage to plant roots produces little injury and thus management options are only directed at adult stages.

In this study, traps were examined as an alternative means of managing the insect. Traps can be either attractive, relying on physical or chemical stimulus to lure insects into them, or passive, collecting insect incidentally. Traps with chemical stimuli (i.e., pheromones and allelochemicals) may be used in surveys to monitor for the arrival and/or suppression of a certain pest species. Traps can also be used as a method for monitoring pest populations in the field so that timing of pesticide applications can be directed toward the most vulnerable or most damaging pest life stage and/or to determine whether an insecticide application to fields is justified (exceeds the action threshold).

Visually-based (shape and/or color) traps have been used effectively for monitoring a variety of insect pests, especially on tree fruits (Prokopy 1972, Adams et al. 1983). Zittler and Simmons (1980) have reviewed the use of yellow traps as control agents of various pest species. Visual traps have some advantages over other trap types; that they can be used for control or monitoring purposes for which no chemical lure is available. Unlike most pheromone traps, visual traps attract both sexes and attract pest species only from within the approximate area.

Studies of color preference of flea beetle species have produced variable results. Adams and Los (1986) found that Saturn yellow and lightning yellow traps captured significantly more corn flea beetles, *Chaetocnema pulicaria* Melsheimer, than other colors tested in sweet corn fields. Vincent and Stewart (1986) reported that white traps attracted more flea beetles than any other colors tested. In addition to color, the type of trap used to capture flea beetles for monitoring and/or reducing infestation in brassica plantings can also affect trap catch. Lefroy (1914) used the Wisley turnip-fly trap, which gave excellent results in capturing adults of two flea beetle species, *P. consobrina* Curtis and *P. undulata* Kutschera, in turnip plantings.

The shape and the size of the trapping surface may also influence the effectiveness of attracting and thus capturing the target insect. This is probably due to the effect of the trap size and shape on search-image cues (Gross et al. 1983, Levinson and Hoppe 1983) and color cues (Prokopy and Hauschild 1979, Timmons and Potter 1981, Niemeyer 1985). For example, the number of aphids caught in black- or yellow-colored sticky traps decreased as trap size increased (Heathcote 1957). Similarly, Staples and Allington (1959) reported that small grease-coated slides captured larger numbers of eriophyid mites when compared to larger slides. This may be related to the air movement around the surface of small versus large traps. In strong winds, small diameter cylindrical traps used to collect aphids by impaction were found to be most efficient than flat horizontal or flat vertical traps. In slow moving winds, however, the impaction efficiency of any trap surface is small (Taylor and Palmer 1972).

Although the color preference of the western cabbage flea beetle to sticky traps has not been studied, trapping of other cabbage insects has been extensive. Studying the trap color preference of the cabbage root fly, *Delia radicum* (L.), various authors (Dapsis and Ferro 1983, Vernon and Borden 1983, Láska et al. 1986, Kostál 1991, Kostál and Finch 1996) have concluded that the most effective traps for capturing the fly are those painted with colors that reflected a high relative proportion of light in the green-yellow region of the spectrum (i.e., wavelengths of 500-600 nm). It has also been noted that female flies identify host plants based on visual stimuli released as energy above and below 500 nm that is reflected from the host leaves (Prokopy et al. 1983b).

Plant foliage releases visual stimuli in the green-yellow region of the spectrum (Prokopy et al 1983ab, Prokopy and Owens 1983), and thus flea beetles may similarly prefer the same color range to stimulate food and host-finding behavior. It has been suggested that yellow color is attractive to many insects because it reflects light, with more intensity, in the same region of the spectrum as foliage. This makes the yellow appear as a large attractive feeding surface compared to the less reflective foliage background (Prokopy 1968, 1972).

In regard to chemical attractants, brassica plant species synthesize large quantities of glucosinolates which upon hydrolysis are degraded to produce isothiocyanates, sulfate and glucose, nitrile plus sulfur or thiocyanates (Carlson et al. 1987). The glucosinolates are stored in vacuoles and are hydrolyzed to give the active isothiocyanates by the action of cell wall-bound enzyme myrosinase (Chew 1988). When plant tissue is damaged, myrosinase is released to hydrolyze glucosinolates and produce volatile compounds, most interestingly isothiocyanates. Isothiocyanates, more commonly known as the mustard oils, have been implicated in host plant selection in several insect species, including some flea beetle species, *P. cruciferae* Goeze and *P. striolata* Fabricius (Hicks 1974, Hicks and Tahvanainen 1974). The mustard oil allyl isothiocyanate, a compound already implicated as an allelochemical (Muller 1969), has been proven to be a powerful attractant to flea beetles (Feeny et al. 1970, Burgess 1984). In a trapping experiment using nine isothiocyanate or mustard oils and three nitriles (volatile glucosinolate hydrolysis products), Pivnick et al. (1992) reported that *P. cruciferae* and *P. striolata* were more attracted to allyl isothiocyanate than any other compounds.

Chemical attraction rather than response to physical or chemical properties of the plants is responsible for host plant attraction by *P. cruciferae* and *P. striolata* (Feeny et al. 1970). Only plants containing glucosinolates were chosen as flea beetle hosts. However, flea beetles sometimes cannot distinguish between glucosinolates emitted from a preferred host plant and those emitted from other host plants. The horseradish flea beetle, *P. armoraciae* Koch, for example, cannot recognize its host based only on the glucosinolates of horseradish over other brassica plants (Nielsen et al. 1979). Similarly, the striped flea beetle, *P. striolata*, and the crucifer flea beetle, *P. cruciferae*, do not discriminate between host plant and non-host plants until after they are very close to or on the plant (Pivnick et al.

1992).

Using allyl isothiocyanate in color traps may elicit different response than using the color traps without the bait. Vincent and Stewart (1986) reported that white traps baited with allyl isothiocyanate capture two times the numbers of *P. cruciferae* and *P. sriolata* than the traps without the attractant. They also showed that the beetles were strongly attracted to yellow and white colors in the absence of odors. Sometimes, the type or color of the traps used with the attractant does not restrain flea beetles from being strongly attracted to the traps. It has been reported that *P. striolata* is strongly attracted to traps baited with allyl isothiocynate regardless of the type and color of the traps (Lamb 1983).

Chemical stimulus used to attract insects can be used in specialized traps or in traps used for collecting other insects. Boll weevil traps baited with allyl isothiocyanate were used in a study by Burgess (1984) to monitor abundance of *P. striolata* and *P. cruciferae* in rapeseed and canola crops in western Canada. Dispersal rate of the chemical stimulus used in a trap may be affected by the shape and size of the trapping surface (Lewis and Macaulay 1976, Angerilli and McLean 1984). Pivnick et al. (1991) tested several isothiocyanate (mustard oil) compounds using yellow boll-weevil traps for attractiveness to the northern false chinch bug, *Nysius niger* Baker, a pest of mustard crops in the Canadian prairies. They found that ethyl 4-isothiocyanatobutyrate was more attractive than allyl and *n*-propyl isothiocyanates, and 2-phenylethyl isothiocyanate was not attractive.

Whether traps can control a pest species is often debated. Fleming (1969) summarized the use of floral lures and traps for monitoring and suppressing Japanese beetles, *Popillia japonica* Newman. Traps were effectively used in surveys beyond beetleinfested areas to monitor for the arrival of beetles. However, large-scale trapping programs, in which billions of beetles were captured, failed to show that the traps were effective in protecting horticultural crops or plants (Langford et al. 1940, Hamilton et al. 1971, Klein 1981).

The aim of this study was to develop the best trap involving visual and/or chemical cues that could be used for monitoring, mass trapping, and possibly diversion from crop of the western cabbage flea beetle. These studies determined colors that were most attractive to adult flea beetles and if allyl isothiocyanate (AITC), a known attractant to other crucifer-feeding flea beetles, is similarly attractive to the western cabbage flea beetle. The potential use of the crude canola oil as an attractant in suitable traps to help for any trapping purposes of adult western cabbage flea beetles was also investigated.

METHODS AND MATERIALS

Trapping experiments were conducted at the Horticultural Field Research Center (HFRC) and the Agriculture Research Development and Education Center (ARDEC) in Fort Collins, CO. Experiments were performed during the summers of 1996, 1997, and 1998 on naturally occurring populations of flea beetles.

Color Sticky Trap Experiments

Colored sticky trap experiments were only conducted in the summers of 1996 at the HFRC site in plots adjacent to a row of broccoli. Individual plots consisted of a single row, 91 meters in length, planted with broccoli (cv. 'Green Comet', Thompson & Morgan Inc.) on 38-cm in-row spacing. Plants were transplanted on 7 June 1996.

Four different color treatments, Saturn green, Saturn pink, Saturn yellow and white, with transparent sheets as a control, were arranged in a randomized complete block design with four replications. A trap consisted of a colored 12.7 by 7.6-cm index card covered, on each side, with a transparent sheet stapled to the card. For the control trap, only the two transparent sheets were stapled together without the cards in between. Each card was then stapled to a plastic stake (18-cm long) used to hold the trap upward along the row. The two outer surfaces of each trap were coated with a thin layer of Tanglefoot® (The Tanglefoot Co., Grand Rapids, MI). Traps, 4.5 meters apart, were laid out on 21 and 28 June, and evaluated on 28 June and 1 July, respectively. For each evaluation date, upon collection each sticky trap was wrapped with a clear plastic wrap and transferred to the lab for counts of captured beetles.

Allyl Isothiocyanate Experiments

Experiments were conducted in both sites in 1996 and 1997 summer season using allyl isothiocyanate as an attractant. In 1996, six traps arranged in a randomized complete block design were laid out on 12 July and placed at a minimum 6-m spacing in a plot planted with different species of canola located at the ARDEC site. Traps, designed similar to those used by Feeny et al. (1970), consisted of 60-cm high wooden post supporting a 50-cm-long crossbar from the ends of which were suspended two 9-cm-deep by 10-cm-diameter paper cups. Each trap was 50-cm above the ground and about 10-cm above the nearest canola plant. All cups opened north. Cups were lined on the inside with transparent sheets coated with a thin layer of Tanglefoot® to facilitate capture, removal and counting of flea beetles. For each trap, two 15 ml glass vials were used, one filled with 10 ml of a 1% aqueous solution (v/v) of allyl isothiocyanate (AITC) (Sigma Chemical Company), the other, which served as the control, filled with 10 ml distilled water.

A pipestem cleaner was placed inside each vial as a wick to regulate evaporation of the solutions, and each vial then was capped using a red-rubber stopper. The pipestem cleaner was used to move the solution upward by capillary action and so it could be absorbed by the rubber stopper and subsequently release the allyl isothiocyanate from its outer surface (Burgess and Wiens 1980). Allyl isothiocyanate and control vials were placed randomly in each of the two cups of each trap. After one week, the traps were removed on 19 July and transferred to the lab, and the beetles were counted.

In 1997, the same trap design was used as in the previous year with three different concentrations of allyl isothiocyanate tested. Traps, laid out on 3 June in two replications, were arranged in a randomized complete block design with three different concentration treatments (1%, 2%, and 3% of allyl isothiocyanate) with distilled water as a control. In each replication, four traps were placed at least 6-m away from each other, in a row planted with broccoli located at the HFRC site. For each trap, two 15-ml glass vials were used; one was filled with 10 ml of a 1%, 2%, or 3% aqueous solution (v/v) of allyl isothiocyanate, and the other was filled with 10 ml of distilled water. Vials were placed randomly in each of the two cups of each trap. Traps were evaluated on 11 June by removal of traps and counting of captured beetles.

Visual/Olfactory Trap Experiments

A trial using combinations of visual and olfactory stimuli was conducted adjacent to a row of broccoli at the HFRC site in the summer of 1997. Traps, arranged in a randomized complete block design with four replications, were lined up 8-m apart within a single row planted with broccoli (cv. 'Premium Crop') on 38-cm in-row spacing. Plants were transplanted on 19 May, and traps were laid out on 4 July. Trap design consisted of Saturn yellow sticky cards each provided with 3-cm^2 piece of poster paper containing either 1%, 2%, or 3% aqueous solution of allyl isothiocyanate. For the control, the sticky trap was provided with 3^2-cm piece of poster paper containing distilled water. The different concentrations of allyl isothiocyanate and water were absorbed onto the pieces of paper, which were stapled to the center of each sticky trap. Each trap was then stapled to a 50-cm high wooden stakes to hold the traps upward along the row. Trap captures were evaluated on 14 June.

In 1998, a different trapping design was used with the attractant allyl isothiocyanate (AITC) and crude canola oil. Trap design consisted of a yellow cup glued at the bottom to a 30-cm PVC pipe. Another cup, containing ethylene glycol based-antifreeze solution (Safer®), was inserted over the fixed cup as a holding cup to facilitate insect capture and removal of captured insects for counting. Each trap was provided with a film container attached from the inside of the removable cup with a paper clip. Film containers were filled with either 1% of AITC or crude canola oil. Traps were held upward on 120-cm high fence posts. Traps were laid out, at least 5-m away from each other, on 29 July in a randomized complete block design with four replications. Traps were sampled on 3 Aug by taking all captured insects to laboratory for counting. On the same day, 3 Aug, the vials were provided with caps and pipestem cleaners to regulate dispensing. These traps were sampled on 6 August by removal of captured insects and transferring them to the lab for counting.

For all trapping experiments, data were analyzed with two-way ANOVA (SAS institute 1985), testing for the effect of treatments (visual or olfactory stimuli) and block. Analysis was carried out on the mean of captured flea beetles per trap for each treatment for each block. Comparisons of treatments were carried out using Student-Newman-Keuls (SNK) (SAS institute 1985).

RESULTS AND DISCUSSION

The response of western cabbage flea beetles to color traps differed between the two sampling dates (Table 4.1). On the 1 July sampling date, flea beetles responded differently to the different colors. Saturn green and Saturn yellow traps attracted significantly more flea beetles than transparent traps (F=4.36, P=0.0209). However, on the 28 June sampling date, there were no significant difference in flea beetles numbers between colors (F=3.32, P=0.0473).

Flea beetles also responded differently to traps baited with different concentrations of allyl isothiocyanate. Traps baited with allyl isothiocyanate consistently captured significantly more beetles than control traps. In the 1996 trapping experiment (Table 4.2), traps baited with allyl isothiocyanate attracted significantly more flea beetles than the control traps (F=40.97, P=0.0014). Traps with paper cups baited with different concentrations of allyl isothiocyanate showed significant differences in number of adult beetles captured (Table 4.3) (F=13.34, P=0.0306). Traps baited with 2% allyl isothiocyanate caught significantly more flea beetles than the control. However, yellow-colored sticky traps baited with different concentrations of allyl isothiocyanate, showed no significant differences in number of flea beetles captured among the different concentrations (Table 4.4) (F=2.67, P=0.1111).

Table 4.1. Mean numbers of western cabbage flea beetle adults captured on sticky traps of various colors placed in a plot of broccoli, Colorado State University Horticulture Field Research Center, Fort Collins, CO, 1996.

	No. of Flea Beetles / Trap[a]	
Trap Color	24-June	1-July
Transparent (Control)	80.75 a	110.50 b
White	114.50 a	175.00 a
Saturn Yellow	138.00 a	190.25 a
Saturn Pink	83.75 a	152.25 ab
Saturn Green	124.75 a	209.50 a

[a]Means within a column followed by the same letter are not significantly different (P=0.05) by SNK. Means are based on captures per trap from 21 June to 28 June and from 26 June to 1 July; 4 replicates of each treatment per date.

Table 4.2. Mean numbers of western cabbage flea beetle adults captured on dual paper cup traps baited with glass vials containing allyl isothiocyanate in a plot of canola, Colorado State University Agriculture Research Development and Education Center, Fort Collins, CO, 1996.

Treatment	No. of Flea Beetles / Trap[a]
Allyl Isothiocynate	173.5 a
Water (Control)	84.67 b

[a]Means within a column followed by the same letter are not significantly different (P=0.05) by SNK. Means are based on captures per trap from 12 July to 19 July; 6 replicates of each treatment.

Table 4.3. Mean numbers of western cabbage flea beetle adults captured on dual paper cup traps baited with glass vials containing different concentrations of allyl isothiocyanate placed in a plot of broccoli, Colorado State University Horticulture Field Research Center, Fort Collins, CO, 1997.

Treatment and concentration	No. of Flea Beetles / Trap[a]
Allyl Isothiocyanate - 1%	245.50 ab
Allyl Isothiocyanate - 2%	365.50 a
Allyl Isothiocyanate - 3%	215.50 ab
Water (Control)	107.50 b

[a]Means within a column followed by the same letter are not significantly different (P=0.05) by SNK. Means are based on captures per trap from 3 June to 11 June; 4 replicates of each treatment.

Table 4.4. Mean numbers of western cabbage flea beetle adults captured on yellow sticky traps baited with squared poster papers containing different concentrations of allyl isothiocyanate placed in a plot of broccoli, Colorado State University Horticulture Field Research Center, Fort Collins, CO, 1997.

Treatment	No. of Flea Beetles / Trap[a]
Allyl Isothiocyanate - 1%	23.25 a
Allyl Isothiocyanate - 2%	20.50 a
Allyl Isothiocyanate - 3%	32.50 a
Water (Control)	21.50 a

[a]Means within a column followed by the same letter are not significantly different (P=0.05) by SNK. Means are based on captures per trap from 4 June to 14 June; 4 replicates of each treatment.

In the 1998 trial, western cabbage flea beetles responded significantly to traps baited with allyl isothiocyanate. Traps baited with allyl isothiocyanate caught significantly more beetles than traps using canola oil or water (control) on both sample dates (Table 4.5) (F=11.92, P=0.02; F=32.23, P=0.0006, respectively). There were no significant differences in the number of flea beetles caught in traps baited with canola oil and the control on both sample dates (Table 4.5). The number of flea beetles captured in all treatments was large on the 7 August sampling date as compared to the 3 August sampling date. The increased captures in traps on the August 7 sampling date might be related to the change made in the trap design (adding caps and pipestem cleaners to regulate dispensing) making them more attractive.

Incidentally, the false chinch bug *Nysius raphanus* Howard (Hemiptera: Lygaeidae), a pest of brassica plants and others, was caught in high numbers in the allyl isothiocyanate- and canola oil-baited traps (Table 4.6). False chinch bugs also showed strong allyl isothiocyanate and moderate canola oil preference. On the 3 and 7 August sampling dates, the number of false chinch bugs captured in allyl isothiocyanate baited traps was significantly different than the canola oil and control traps (F=7.61, P=0.04; F=34.10, P=0.0005, respectively). On the 7 August sampling date, however, canola oil attracted significantly greater numbers than the control.

Table 4.5. Mean numbers of western cabbage flea beetle adults captured on yellow cup traps baited with film canisters containing allyl isothiocyanate or canola oil placed in a plot of canola, Colorado State University Agriculture Research Development Center, Fort Collins, CO, 1998.

Treatments	No. of Flea Beetles / Trap[a]	
	3-Aug	7-Aug
Control	0.67 b	23.75 b
Allyl Isothiocyanate - 1%	15.67 a	204.00 a
Canola Oil	3.33 ab	43.25 b

[a]Means within a column followed by the same letter are not significantly different (P=0.05) by SNK. Means are based on captures per trap from 29 July to 3 August and from 3 August to 7 August; 4 replicates of each treatment per date.

Table 4.6. Mean numbers of false chinch bugs captured on yellow cup traps baited with film canisters containing allyl isothiocyanate or canola oil placed in a plot of canola, Colorado State University Agriculture Research Development and Education Center, Fort Collins, CO, 1998.

Treatments	No. of False Chinch Bugs / Trap[a]	
	3-Aug	7-Aug
Water (Control)	17.3 b	3.25 c
Allyl Isothiocyanate - 1%	401.7 a	162.75 a
Canola Oil	212.3 ab	23.75 b

[a]Means within a column followed by the same letter are not significantly different (P=0.05) by SNK. Means are based on captures per trap from 29 July to 3 August and from 3 August to 7 August; 4 replicates of each treatment per date.

The 1996 trap color preference evaluation showed that Saturn green and Saturn yellow, with reflection wavelengths between 500-600 nm, are attractive to flea beetles. This is similar to that found in trapping trials of other cabbage pest species. For example, many studies (Finch and Skinner 1974, Dapsis and Ferro 1983, Vernon and Borden 1983, Láska et al. 1986, Kostál 1991, Finch 1992) have shown that the cabbage root fly prefers the yellow color to others. This preference of the yellow color has been interpreted as a reaction to a stimulus comparable to that from green-yellow plant foliage (Prokopy et al. 1983ab, Prokopy and Owens 1983).

The present study showed that western cabbage flea beetle is also attracted to yellow and green suggesting that the beetles use the visual stimuli detected from leaves in the yellow-green region of spectrum when searching for host. Adult flight activity of western cabbage flea beetle has been reported to occur primarily during the middle of the day (Chittenden and Marsh 1920). Since beetles were caught on transparent traps, it is also possible that the high activity of adult flea beetles causes some to come into contact with the traps simply through random movement.

This study is the first to identify allyl isothiocyanate as an effective attractant for *P. pusilla*. Results were consistent with those of other studies with other beetle species in which allyl isothiocyanate was attractive. Feeny et al. (1970) tested allyl isothiocyanate on two related *Phyllotreta* species, *P. cruciferae* and *P. striolata*; they reported that the allyl isothiocynate is a powerful attractant to both species. In a similar test, *P. cruciferae and P. striolata*, were strongly attracted to allyl isothiocyanates and weakly or not attracted to other volatile glucosinolate hydrolysis products (Pivnick et al. 1992). In a contrasting finding, Blight et al. (1989) reported the cabbage stem flea beetle, *Psylliodes chrysocephala* L., had a strong electroantennogram response to three other isothiocyanates but not to allyl isothiocyanate.

Traps baited with canola oil attracted fewer numbers of flea beetles compared to allyl isothiocyanate. This may be due to low chemical release for the canola oil to attract flea beetles or due to the presence of other isothiocyanates in the canola oils that are weakly attractive to flea beetles as compared to allyl isothiocyanates. Beside flea beetles, false chinch bugs (*N. raphanus*) showed strong preference to allyl isothiocyanate and lesser preference to the canola oil. Similarly, Pivnick et al. (1991) reported that the northern false chinch bug, *Nysius niger* Baker, was strongly attracted to allyl isothiocyanates. The large difference between 3 and 7 August trap captures is probably due to changes made to the film canisters holding the chemical baits. Adding caps and pipestem cleaners to regulate evaporation may have improved the effectiveness of the traps.

Using pieces of poster paper in yellow sticky traps as the release surface for allyl isothiocyanate was not encouraging. This may be due to the low release rate of allyl isothiocyanate or that the allyl isothiocyanate faded much faster that low number of flea beetles were attracted. It is also possible that flea beetles captured in these traps were attracted to the yellow color rather than the chemical lure. Vincent and Stewart (1986) reported that the flea beetles *P. striolata* and *P. cruciferae* were strongly attracted to yellow and white traps in the absence of odors. It has been noted (Lewis and Macaulay 1976, Angerilli and McLean 1984) that chemical dispersal can be affected by the shape and size of the trapping surface reducing the efficiency of attracting and capturing insects.

The concentration response trial with allyl isothiocyanate implies that an increase in allyl isothiocyanate concentration up to 2% would increase the attractiveness of the traps. In contrast, increasing the concentration of allyl isothiocyanate above 2% (i.e., 3%) may reduce its attractiveness; possibly due to a deterrent effect of the higher concentration of allyl isothiocyanates.

In general, traps may provide an effective control measure, as well as provide an excellent monitoring tool for flea beetles. Traps baited with a chemical attractant (i.e., allyl isothiocyanate) may be used in Integrated Pest Management (IPM) programs in surveys to monitor for the arrival and/or suppression of flea beetles. Traps can also be used as a method for monitoring adult flea beetle populations in the field and to determine whether an insecticide application to fields of brassica crop is warranted. Scouting for western cabbage flea beetle density is sometimes misleading because flea beetle adults are very active and may quickly hop or fly away before they are monitored. Environmental conditions, such as winds, rains, hot or humid weather may also affect flea beetle activity so that scouting at a particular point in time may not provide an accurate representation of the population. This is of particular importance in developing action threshold strategy for controlling adult flea beetles.

Traps can be used to monitor populations of western cabbage flea beetle to improve timing, and thus the effectiveness, of insecticides applied against this pest. When using an action threshold strategy for applying insecticides to a field, traps may be used to determine whether or not such an application is warranted. Since the adults are the damaging stage for this pest species, trap catches of high numbers of adults is indication to apply insecticides. The traps can then be used afterward to investigate the effectiveness of the application in reducing the beetles' population.

The above results have shown that the western cabbage flea beetle can be caught with cheap, simply designed color traps and allyl isothiocyanate baited traps. Traps used in this study are easy to prepare and install in the field and have few non-target effects compared to insecticides. Such features make these traps very easy to implement by any grower. Canola oil, which is much safer and easier to use compared to allyl isothiocyanate, also shown to be attractive, but less so than allyl isothiocyanate.

REFERENCES CITED

Adams. R. J., and L. M. Los. 1986. Monitoring adult flea beetles (Coleoptera: Chrysomelidae) in sweet corn fields with color sticky traps. Environ. Entomol. 15: 867-873.

Adams, R. G., C. H. Domeisen, and L. J. Ford. 1983. Visual traps for monitoring pear psylla adults on pears. Environ. Entomol. 12: 1327-1331.

Angerilli, N. and J. A. McLean. 1984. Windtunnel and field observations of western spruce budworm responses to pheromone-baited traps. J. Entomol. Soc. Brit. Columbia 81: 19-16.

Blight, MM, J. A. Pickett, L. J. Wadhams, and C. M. Woodcock. 1989. Antennal responses of *Ceutorhynchus assimilis* and *Psylliodes chrysocephala* to volatiles from oilseed rape. Aspects Appl. Biol. 23: 329-334.

Burgess. L. 1984. Changes in relative abundance of the flea beetles Phyllotreta striolata and *Phyllotreta cruciferae* (Coleoptera: Chrysomelidae) in Saskatchewan parkland with increasing distance from the boreal forest. Can. Entomol. 116: 653-656.

Burgess, L. and J. E. Wiens. 1980. Dispensing allyl isothiocyanate as an attractant for trapping crucifer-feeding flea beetles. Can. Entomol. 112: 93-97.

Carlson, D. G., M. E. Daxenbichler, C. H. VanEtten, W. F. Kwolek, and P. H. Williams. 1987. Glucosinolates in crucifer vegetables: broccoli, Brussels sprouts, cauliflower, collards, kale, mustard greens, and kohlrabi. J. Am. Soc. Hort. Sci. 112: 173-178.

Chew, F. S. 1988. Biological effects of glucosinolates. Pp. 155-181. *In* HG Cutler (ed.), Biologically active natural products: potential use of in agriculture. American Chemical Society Symposium Series no. 380. Am. Chem. Soc., Washington, DC.

Chittenden, F. H. and H. O. Marsh. 1920. The western cabbage flea beetle. USDA, Bulletin No. 902. 21 pp.

Dapsis, L. J., and D. N. Ferro. 1983. Effectiveness of baited cone traps and coloured sticky traps for monitoring adult cabbage maggots: with notes on female ovarian development. Entomol. Exp. et Appl. 33: 35-42.

Feeny, P., K. L. Paauwe, and N. J. Demong. 1970. Flea beetles and mustard oils: host plant specificity of *Phyllotreta cruciferae* and *P. striolata* adults (Coleoptera: Chrysomelidae). Ann. Entomol. Soc. Amer. 63: 832-841.

Finch, S. 1992. Improving the selectivity of water traps for monitoring populations of the cabbage root fly. Ann. Appl. Biol. 120: 1-7.

Finch, S. and G. Skinner. 1974. Some factors affecting the efficiency of water traps for capturing cabbage root flies. Ann. Appl. Biol. 74: 213-216.

Fleming, W. E. 1969. Attractants for the Japanese beetle. USDA-ARS Tech. Bull. 1399.

Gross, H. R., Jr., J. E. Carpenter, and A. N. Sparks. 1983. Visual acuity of *Heliothis zea* (Lepidoptera: Noctuidae) males as a factors influencing the efficiency of pheromone traps. Environ. Entomol. 12: 844-847.

Hamilton, D. W., P. H. Schwartz, B. G. Townsend, and C. W. Jester. 1971. Traps reduce an isolated infestation of Japanese beetle. J. Econ. Entomol. 64: 150-153.

Heathcote, G. D. 1957. The optimum size of sticky aphid traps. Plant Pathol. 6: 104-107.

Hicks, K. L. 1974. Mustard oil glucosides: Feeding stimulants for adult cabbage flea beetles, *Phyllotreta cruciferae*. Ann. Entomol. Soc. Am. 67: 261-264.

Hicks, K. L., and J. O. Tahvanainen. 1974. Niche differentiation by crucifer feeding flea beetles (Coleoptera: Chrysomelidae). Amer. Midl. Nat. 91: 406-423.

Klein, M. G., J. M. Tumlinson, T. L. Ladd and R. E. Doolittle. 1981. Japanese beetle (Coleoptera: Scarabaeidae): response to synthetic attractant plus phenethyl propionate: eugenol. J. Chem. Ecol. 7: 1-6.

Kostál, V. 1991. The effect of colour of the substrate on the landing and oviposition behaviour of the cabbage root fly. Entomol. Exp. et Appl. 59: 189-196.

Kostál, V. and S. Finch. 1996. Preference of the cabbage root fly, *Delia radicum* (L.) for coloured traps: influence of sex and physiological status of the flies, trap background and experimental design. Physiol. Entomol. 21: 123-130.

Lamb, R. J. 1983. Phenology of flea beetle (Coleoptera: Chrysomelidae) flight in relation to their invasion of canola fields in Manitoba. Can. Entomol. 115: 1493-1502.

Langford, G. S., S. L. Crostwait and F. B. Whittington. 1940. The value of traps in Japanese beetle control. J. Econ. Entomol. 33: 317-320.

Láska, P., I. Zelenková and V. Bicik. 1986. Colour attraction in species of the genera *Delia* (Diptera: Anthomyiidae): *Ceutorhynchus*, *Meligethes* and *Phyllotreta* (Coleoptera: Curculionidae, Nitidulidae, Chrysomelidae). Acta Entomologica Bohemoslovaca 83: 418-424.

Lefroy, H. M. 1914. Contributions from the Wisley laboratory. XXHI. A trap for turnip fly. J. Roy. Hort. Soc. Engl. 40: 269-271.

Levinson, H. Z., and T. Hoppe. 1983. Preferential flight of *Plodia interpunctella* and *Cadra cautella* (Phycitinae) toward figures of definite shape and position with notes on the interaction between optical and pheromone stimuli. Z. Ang. Entomol. 96: 491-500.

Lewis, T. and E. D. M. Macaulay. 1976. Design and elevation of sex-attractant traps for pea moth, *Cydia nigricana* (steph.) and the effect of plume shape on catches. Ecol. Entomol. 1: 175-187.

Muller, C. H. 1969. Allelopathy as a factor in ecological process. Vegetation 18: 348-357.

Nielsen, J. K., L. Dalgaard, L. M. Larson, and H. Sorensen. 1979. Host plant selection of the horse-radish flea beetle *Phyllotreta armoraciae* (Coleoptera: Chrysomelidae): feeding responses to glucosinolates from several crucifers. Entomol. Exp. et Appl. 25: 227-239.

Niemeyer, H. 1985. Field response of *Ips typographus* L., (Col., Scolytidae) to different trap structures and white versus black flight barriers. Z. Ang. Entomol. 99: 44-51.

Pivnick, K. A., Reed D. W., J. G. Millar and E. W. Underhill. 1991. Attraction of northern false chinch bug *Nysius niger* (Heteroptera: Lygaeidae) to mustard oils. J. Chem. Ecol. 17: 931-941.

Pivnick, K. A., R. J. Lamb and D. Reed. 1992. Response of flea beetles, *Phyllotreta* spp., to mustard oils and nitriles in field trapping experiments. J. Chem. Ecol. 18: 863-873.

Prokopy, R. J. 1968. Visual responses of apple maggot flies, *Rhagoletis pomonella* (Diptera: Tephritidae): orchard studies. Entomol. Exp. et Appl. 11: 403-422.

Prokopy, R. J. 1972. Response of apple maggot flies to rectangles of different colors and shades. Environ. Entomol. 1: 720-726.

Prokopy, R. J., RH Collier and S. Finch. 1983a. Visual detection of host plants by cabbage root flies. Entomol. Exp. et Appl. 34: 227-234.

Prokopy, R. J., R. H. Collier and S. Finch. 1983b. Leaf colour used by cabbage root flies to distinguish among host plants. Science 221: 190-192.

Prokopy, R. J., and K. I. Hauschild. 1979. Comparative effectiveness of sticky red spheres and Pherocon® AM standard traps for monitoring apple maggots flies in commercial orchards. Environ. Entomol. 8: 696-700.

Prokopy, R. J. and E. D. Owens. 1983. Visual detection of plants by herbivorous insects.

Ann. Rev. Entomol. 28: 337-364.

SAS Institute. 1985. SAS user's guide: Statistics, 5th ed. SAS Institute, Cary, NC.

Staples, R. and W. B. Allington. 1959. The efficiency of sticky traps in sampling epidemic populations of eriophyid mite *Aceria tulipae* (K.), vector of wheat streak mosaic virus. Ann. Entomol. Soc. Am. 52: 159-164.

Taylor, L. R. and J. M. P. Palmer. 1972. Aerial sampling. Pp. 189-234. *In* H. F. van Emden (ed.), Aphid Technology. Academic Press, New York.

Timmons, G. M. and D. A. Potter. 1981. Influence of pheromone trap color on capture pf lilac borer males. Environ. Entomol. 19: 756-759.

Vernon, R. S. and J. H. Borden. 1983. Spectral specific discrimination by *Hylemya antiqua* (Meigen) (Diptera: Anthomyiidae) and other vegetable-infesting species. Environ. Entomol. 12: 650-655.

Vincent, C. and R. K. Stewart. 1986. Influence of trap color on captures of adult crucifer-feeding flea beetles. J. Agric. Entomol. 3: 120-124.

Zittler, T. A. and J. N. Simmons. 1980. Management of viruses by alteration of vector efficiency and by cultural practices. Ann. Rev. Phytopathol. 18: 289-310.

CHAPTER V

FIELD EVALUATION OF DIFFERENT INSECTICIDES AND REPELLENTS FOR WESTERN CABBAGE FLEA BEETLE CONTROL ON BRASSICA CROPS

INTRODUCTION

The western cabbage flea beetle, *Phyllotreta pusilla* Horn (Chrysomelidae: Coleoptera), is a major pest in brassica crop fields and in other brassica plantings. The western cabbage flea beetles can also be a serious pest of a wide variety of vegetable crops. In addition to brassica crops, they also attack beans, peas, sugarbeets and other nonbrassica vegetable crops (Chittenden and Marsh 1920). This species, very common throughout Colorado, is particularly damaging to producers of Certified Organic produce for whom management options are limited (Cranshaw, personal communication).

The main injury is caused by the overwintered beetles moving into newly planted brassica crops. Adult flea beetle injury to plants consists of small pits or holes eaten in the leaves and may range from a few "shot-holes", to severe stress to young plants, to complete destruction and death of the plant. The beetles can appear suddenly in huge numbers, and large areas may be devastated before the grower becomes aware of their presence. Feeding injury by the beetles is most severe when seedlings, particularly at emergence when only the cotyledons are present, are attacked. Damage to plants continues beyond the seedling stage and may intensify with the emergence of the summer generation (Chittenden and Marsh 1920).

Management is usually only directed at adult flea beetles early in spring when brassica crops are small and most susceptible to defoliation; larvae confine their feeding to the roots of brassica plants and cause little appreciable damage. The control of the larval stage is, thus, not generally economical. Later generations of adult flea beetles can cause some feeding damage but brassica plants are able to compensate for this injury through increased summer growth. Leafy brassicas, however, can sustain serious cosmetic damage from later generations.

Insecticides are considered the primary control against this pest, particularly in early spring when plants are small and sensitive to defoliation. This is because flea beetle management strategies, except for insecticides, either have not been identified (e.g., plant resistance) (Lamb 1980) or have not been successful (e.g., planting date manipulations) (Lamb 1984) in either the United States or Canada. There are also no effective biological control agents available to control flea beetles. Moreover, adult flea beetles are strong fliers and can migrate to nearby fields or be carried by the wind for long distance migration. Therefore, long-term control may require more than one application to control for flea beetles migrating from another fields. When adult populations are low and growing conditions are favorable, chemical application may not be necessary.

Attempts to control this insect with various insecticides and repellents have continued over a century, with some proven success. In the late 1800s, Howard (1898) demonstrated that application of a strong solution of soap suds killed beetles instantly and that sprinkling a mixture of wetted fresh cow manure on the plant would drive the beetle away. In the early 1900s, Chittenden and Marsh (1920) reported that foliar application of insecticides did not kill the beetles but drove them away from the treated areas; the beetles were repelled away from treated plants and moved to feed on untreated plants or untreated parts of a plant. It has also been noted that the application of repellents and deterrents (e.g., tobacco dust and arsenicals) work more effectively against this insect (Chittenden 1903, Chittenden and Marsh 1920). Arsenicals, Paris green in particular, were found to be the most useful treatment against the flea beetle. In addition, mixing Bordeaux mixture, which was extremely distasteful to flea beetles, with the insecticide and applied as a spray gave more effective results than using it dry. Bordeaux mixture when used alone also gave feeding deterrent effects (Chittenden 1903).

Other species of flea beetle have been effectively controlled with insecticides. Alford (1977) reported that the application of carbofuran as 5% granules, on winter oil-seed rape, gave 100% larval control of the cabbage stem flea beetle, *Psylliodes chrysocephala* (L.). He also found that two other granular insecticides, fonofos and phorate, also were effective. Two flea beetle species, *Phyllotreta cruciferae* Goeze and *Phyllotreta striolata* (F.), attacking spring oilseed rape (*Brassica rapa* L.) grown in western Canada, are effectively controlled by systemic insecticides applied at the time of seeding (Lamb et al. 1993).

In Canada, growers protect canola seedlings by applying soil insecticides at seeding (Lamb 1989). Flea beetles attacking rapeseed in Manitoba have been successfully controlled by using insecticides as a seed treatment, as post-emergence sprays, or by using a combination of seed treatment plus one or more post-emergence sprays (Findlay 1976). In Ontario, larvae of the cabbage flea beetle, *P. cruciferae*, were incidentally controlled as cyclodiene insecticides were applied to the soil for the control of other insects pests (i.e., cabbage maggot and cutworms). When cyclodienes were not applied to the soil, insecticides such as DDT or endrin, applied regularly as foliar sprays, provided effective beetle control (Harris and Gore 1970). After the abandonment of the cyclodienes, other alternative insecticides, applied regularly as foliar sprays, were reported to have effectively reduced flea beetle incidents including endosulfan, methyl trithion®, phosphamidon, and methoxyclor (Ratcliffe et al. 1961, Young and Ditman 1959).

Harris and Gore (1970) tested the contact toxicity of 32 insecticides to flea beetle adults and reported that carbofuran and mevinphos were the most effective insecticides tested. They also reported that carbofuran and chlorfenvinphos applied at low concentrations at weekly intervals provided effective flea beetle control in field trials. Deltamethrin applied at the onset of adult stage or at early larval invasion gave excellent control of *P. chrysocephala* (Black and Hewson 1984). Roos and Tappan (1972) reported that the tobacco flea beetle, *Epitrix hirtipennis* (Melsheimer), is effectively controlled by parathion and Zectran®.

Munkvoid et al. (1996) studied the effect of imidacloprid seed treatment on corn leaf feeding and transmission of Stewart's disease by the corn flea beetle, *Chaetocnema pulicaria* Melsheimer. They reported that corn plants grown from seeds treated with imidacloprid had significantly fewer flea beetle scars (reduced flea beetle feeding) and fewer leaves with symptoms than control plants. The authors also reported that the frequency of Stewart's disease transmission was reduced significantly by imidacloprid treatment. They concluded that imidacloprid can be an effective deterrent to flea beetle feeding and transmission of Stewart's disease by the corn flea beetle.

Research on alternative methods for controlling insect pests has increased greatly in recent years because of persistent problems with reliance on conventional insecticides. These problems include the "three Rs", insect resistance, replacement and resurgence, as well as environmental contamination. The use of behavior-modifying compounds such as feeding repellents or deterrents that can reduce insect feeding without killing them has appeal because of their minimal effects to non-target organisms as compared to broad-spectrum toxic compounds. Several studies have been conducted to investigate the use of such compounds for control of various pest species (see reviews by Frazier 1986, Norris 1986, and Jermy 1990). Although brassica crop pests have historically been controlled with synthetic organic insecticides, recent public concerns about the use of these insecticides and their adverse effects have resulted in a demand for crops grown without the use of these materials. Therefore, alternative management tools to synthetic organic insecticides are being developed and many are currently being marketed (Endersby and Morgan 1991).

Neem products, extracted from the neem tree *Azadirachta indica*, have been used for centuries to protect agricultural crops and stored products from insect invasion (Saxena 1987). Azadirachtin, the primary active ingredient of neem extracts, have been reported to have insecticidal properties against more than 200 species of pest insects of various orders, including Coleoptera (Meisner and Mitchell 1982, Abdul Kareem et al. 1989, Schmutterer and Hellpap 1989). Meisner and Mitchell (1982) have reported that azadirachtin and some other neem extracts have antifeedant activity against the flea beetle, *P. striolata*, on radish.

Biorational insecticides, such as insecticidal surfactants (e.g., detergents and soaps), mineral and certain plant extracts, have also shown potential in controlling pest species on different crops. Edelson et al. (1993) evaluated biorational (i.e., *Bacillus thuringiensis*, fatty acid soap, and release of *Chrysoperla carnea* (Stephens)) and synthetic organic insecticide application regimes for control of key pests of broccoli in southern Texas and reported that the biorational and synthetic organic insecticides were equally effective in controlling lepidopterous pests. They have noted, however, that the biorational regime requires a greater number of applications for effective control. They have also found that the application of synthetic organic insecticides was effective when applied only for aphid control or as a control for lepidopterous larvae. Hough-Goldstein and Hahn (1992) investigated the effects of tansy extract on imported cabbageworm and diamondback moth feeding, and reported that the aqueous extract of tansy reduced feeding on leaf disks by imported cabbageworm and reduced diamondback moth number on plants. When they did insect damage ratings at harvest, they found damage was significantly lower for tansy-treated plants than for plants treated with water.

Several insecticides are currently registered for flea beetles. These include esfenvalerate (Asana), carbaryl (Sevin), disulfoton (Di-Syston), sodium fluoaluminate (Kryocide), methoxychlor, parathion, and pyrethrins (Pyrellin) (Ells et al. 1998abc). However, biorational formulations have not been tested for control of *P. pusilla*. The objective of this study was to investigate the effectiveness of various insecticides and feeding repellents against the western cabbage flea beetle, *P. pusilla*, under field conditions.

METHODS AND MATERIALS

Efficacy trials of various insecticide and repellent formulations for the control of the western cabbage flea beetle were conducted at the Horticulture Field Research Center in Ft. Collins, CO. The insecticide efficacy trials were performed during the summer of 1996 and 1997; repellent trials were performed in 1996, 1997 and 1998. Plants for each trial were grown in the greenhouse for about four weeks prior to field transplanting. After transplanting into the field, broccoli plants were grown under standard husbandry practices. Weeds were controlled by hand when necessary. All experiments were conducted on populations of naturally occurring western cabbage flea beetle adults. Insecticides were applied using a CO_2 compressed air sprayer delivering 23 l/ha at 2.1 kg/cm in two passes directed along the sides of the planting. Liquid repellents were applied to plants using hand-held sprayers to the point of run-off. Dusts (i.e., sulfur and diatomaceous earth) were applied with a Dustin Miser® hand-cranked duster. The effectiveness of treatments was assessed by counting the number of live adults in the sample of four to six plants taken from the center area of each plot. Counting of flea beetle adults was similar to that described before.

Insecticide Efficacy Trials

In the 1996 trial, individual plots consisted of single rows, 6-m in length (38-cm in-row spacing), arranged in a randomized complete block design with four replications. Broccoli plants (cv. 'Premium Crop', The Rocky Mountain Seed Co.) were transplanted on 13 May. Seven different insecticides plus an untreated control were used in this year's trials. These include zeta-cypermethrin (Mustang® 1.5EW, FMC Corp.), 42 g ai/ha; cyhalothrin (Warrior® 1E, FMC Corp.), 0.2 l/ha; fipronil (Fipronil® 1.67SC, Rhone-Poulenc), 50 g ai/ha; carbaryl (Sevin® XLR-plus, Rhone-Poulenc), 2.3 l/ha; esfenvalerate (Asana® XL, DuPont, EI de Nemours & Inc.), 0.54 l/ha; endosulfan (Thiodan® 3E, FMC Corp.), 3.5 l/ha; and imidacloprid (Provado® 1.6, Bayer AG), 0.27 l/ha. Insecticide applications were made 3 June and 21 June, and insect counts were made on 4, 6, 11, 18, 20, 24, and 28 June, and 1 and 11 July by whole plant examination of six plants in each plot of each replicate.

In the 1997 trials, individual plots consisted of single rows, 4.5-m in length (30-cm in-row spacing). Mustard plants (cv. 'Green Wave', The Rocky Mountain Seed Co.) were transplanted on 4 June. Eight insecticides and an untreated control were tested for this year's trials. These include carbaryl (Sevin® XLR), 2 l/ha; imidacloprid (Provado® 1.6), 0.2 l/ha; methomyl (Lannate® 90SP, DoPont), 1.1 kg ai/ha; cypermethrin (Ammo® 2.5E, FMC Corp.), 0.3 l/ha; endosulfan (Thiodan® 3E), 3 l/ha; permethrin (Ambush® 2E, Zeneca Ag. Products), 0.9 l/ha; zeta-cypermethrin (Mustang® 1.5 EW), 42 and 50 g/ha; and fipronil (Agenda® 1.67, Rhone-Poulenc), 56 g ai/ha. Insecticide applications were made 14 June and 27 June, and insect counts were made on 16, 18, 20, 23, 26, and 30 June, and 2, 9, 16, and 21 July by whole plant examination of six plants in each plot.

Repellent Efficacy Trials

In the 1996 repellent efficacy trials, individual plots consisted of single rows, 3-m in length (38-cm in-row spacing), arranged in a randomized complete block design with six replications. Each plot consisted of eight plants. Broccoli plants (cv. 'Premium Crop', The Rocky Mountain Seed Co.) were transplanted on 13 May. Three repellent formulas were used including horticultural oil (SunSpray®, Sun Refining & Marketing Co.), 2% v:v; azadirachtin (Margosan-O®, Ringer Corp.), 1:150 v:v; and garlic extract (Guardian®, American Biochemical Corp.), 10% v:v. Repellents were applied on 20 and 30 May, as well as 3 and 24 June with hand-held sprayers. Plants were sprayed to the point of run-off delivering a spray volume of approximately 167-ml for each plot. Insect counts were made on 21 and 31 May, 4, 6, 11, 20, 24, and 28 June, and 1 and 11 July by whole plant examination of four plants in the center of each plot.

In the 1997 repellent efficacy trials, individual plots consisted of single rows, 6-m in length (38-cm in-row spacing) arranged in a randomized complete block design with four replications. Each plot consisted of 16 plants. Broccoli (cv. 'Premium Crop') was transplanted on 19 May. Four repellent formulas were used in the 1997 efficacy trials. These include horticultural oil (SunSpray®), 2% v:v; garlic extract (Guardian®), 10% v:v; azadirachtin, Azatin® (Fermone), 2.5% v:v, and Trilogy® (W.R. Grace & Co.), 2% v:v. Repellent treatments were applied on 4, 10, 17 and 27 June with hand-held sprayers. Plants were sprayed to the point of run-off delivering a spray volume of approximately 334-ml for each plot. Insect counts were made on 4, 6, 7, 10, 11, 13, 17, 18, 20, 23 and 28 June, and 4 July by whole plant examination of five plants in the center of each plot.

In 1998, three different trials were conducted using different repellent formulas. In the first trial, broccoli (cv. 'Premium Crop') was transplanted on 18 May in plots consisted of single rows, 4-m in length (46-cm in-row spacing) arranged in a randomized complete block design with four replications. Each plot consisted of nine plants. This trial tested four repellents including azadirachtin (Azatin®), 2.5%; Hot Pepper Wax® (Hot Pepper Wax Inc.), 1:32 v:v; natural organic soap (Jungle Rain,), 1:16 v:v: and horticultural oil (SunSpray®), 1:50 v:v. Treatments were applied on 28 May and 2, 10 and 25 June to the point of run-off. Insect counts were made on 1, 3, 10, 11, 15, 19, 28 and 30 June, and 4 July and 1 and 6 July by whole plant examination of five plants in the center of each plot.

The second trial in the 1998, plots were established by transplanting, 3 June, broccoli (cv. 'Green Goliath', Henry Field Seed & Nursery Co.) to single row, at 46-cm in-row spacing. Experimental design was randomized complete block, with four replications and individual plots were 3-m long. Seven repellent formulas were used in the second trial, including the neem-derived formulations Azatin®, 1:800 v:v, and BioNeem® (S.C. Johnson & Son Inc.), 1:40 v:v; garlic extract (Guardian®), 1:10 v:v; Hot Pepper Wax, 1:32 v:v; natural organic soap (Jungle Rain®), 1:16 v:v; Sulfur (Flotox Dusting Sulfur®); and horticultural oil (SunSpray®), 1:50 v:v. Treatments were applied on 11 June to the drip point. Evaluations were made by counting all flea beetles on the center five plants from each plot (7 plants/plot).

In the third trial, broccoli plants (cv. 'Green Goliath') were transplanted on 3 June 1998 at the Horticulture Field Research Center in Ft. Collins, CO. Plots consisted of single row, 3-m in length (46-cm in-row spacing) arranged in a randomized complete block design with four replications. Each plot consisted of seven plants. Seven repellent formulas were used including azadirachtin (BioNeem®), 1:40 v:v; essential oils, clove bud, sage, and sandalwood (Aura Cacia), 5:800 v:v; diatomaceous earth; garlic extract (Guardian®), 1:10 v:v; and sulfur (Flotox Dusting Sulfur®). Repellent treatments were applied on 29 June with plants sprayed to the point of drip. Insect counts were made on 30 June and 1, 6 and 10 July by whole plant examination of five plants from the center of each plot.

To examine the effects of insecticides or repellents on western cabbage flea beetle, data were analyzed with two-way ANOVA (SAS institute 1985), testing for effects of treatments (insecticides or repellents) and block. Analyses were carried out on the mean number of flea beetles per plant for each treatment for each block. Comparisons of the effect of insecticides or repellents on flea beetles were carried out using Student-Newman-Keuls (SNK) (SAS institute 1985).

RESULTS AND DISCUSSION

Insecticide Efficacy Trials

Insecticide-treated plots were found to have significantly lower flea beetles than the controls ($P<0.05$). In the 1996 efficacy trial (Table 5.1), Asana treated plots showed no flea beetles per plant at one day after the first application and at three days after the second application. Although most treatments gave little or no control after eight days from the first application and after ten days from the second application, Thiodan showed promise as an effective control; decreased numbers of flea beetles were observed on Thiodan-treated plants for up to three weeks. Two weeks after the first application and three weeks after the second application, no treatments maintained control. No phytotoxicity was observed on any treated plant.

In the 1997 efficacy trials, all insecticide treatments produced immediate flea beetle suppressant effects (Table 5.2). Flea beetle numbers declined significantly in the Thiodan-treated plots for up to nine days (23 June) after the first application and up to 19 days (16 July) after the second application (F=11.68, P=0.0001; F=4.54, P=0.0010, respectively). Six days after first application and 11 days after the second application increase in flea beetle numbers was observed on Provado-treated plants. No phytotoxicity was observed.

Table 5.1. Mean number of flea beetles per plant observed on broccoli plants receiving foliar application of various insecticides, Colorado State University Horticulture Field Research Center, Fort Collins, Colorado, 1996.

Treatment	Rate	Mean number of Flea Beetles / plant[a]								
		4-June (1 DAT)	6-June (3 DAT)	11-June (8 DAT)	18-June (14 DAT)	20-June (17 DAT)	24-Jun (3 DAT)	28-June (7 DAT)	1-July (10 DAT)	11-July (21 DAT)
Untreated check		5.71 a	2.92 a	8.83 ab	11.50 a	5.38 b	4.58 b	2.29 bc	1.79 b	0.21 a
Mustang	42.00 g/ha	0.33 bc	0.13 c	3.67 ab	12.13 a	5.00 b	0.08 e	0.67 bc	1.54 b	0.92 a
Warrior	0.20 l/ha	0.21 bc	0.08 c	2.88 b	11.38 a	5.92 b	0.25 de	0.38 c	0.71 bc	0.33 a
Fipronil	50.00 g/ha	0.38 bc	0.33 bc	4.08 ab	9.96 a	5.04 b	0.46 d	0.75 bc	0.79 bc	0.54 a
Sevin	2.30 l/ha	0.04 c	0.08 c	5.04 ab	13.75 a	8.29 ab	1.33 c	3.08 ab	1.50 b	0.29 a
Asana	0.54 l/ha	0.00 c	0.17 c	4.75 ab	12.42 a	7.08 ab	0.00 e	0.92 bc	2.46 b	0.42 a
Thiodan	3.50 l/ha	0.25 bc	0.08 c	1.67 c	8.88 a	5.92 b	0.08 e	0.46 bc	0.42 c	0.21 a
Provado	0.27 l/ha	0.83 b	1.04 b	16.21 a	10.58 a	10.25 a	10.08 a	4.75 a	4.13 a	1.25 a

[a]Means within a column followed by the same letter are not significantly different (P=0.05) by SNK test. Means based on 6 cabbage plants per plot for 4 replications.

Table 5.2. Mean number of flea beetles per plant observed on mustard greens plants receiving foliar application of various insecticides, Colorado State University Horticulture Field Research Center, Fort Collins, Colorado, 1997.

Treatment	Rate	Mean number of Flea Beetles / plant[a]									
		16-Jun (2 DAT)	18-Jun (4 DAT)	20-Jun (6 DAT)	23-Jun (9 DAT)	26-Jun (12 DAT)	30-Jun (3 DAT)	2-Jul (5 DAT)	9-Jul (11 DAT)	16-Jul (19 DAT)	21-Jul (24 DAT)
Untreated check		13.09 a	8.03 a	9.38 a	8.84 a	5.19 ab	12.69 a	5.91 a	7.43 a	11.41 a	7.28 ab
Sevin	2.00 l/ha	0.03 c	0.47 bc	4.00 bc	7.75 a	4.38 ab	0.09 b	0.19 b	3.27 b	8.56 ab	6.53 ab
Provado	0.20 l/ha	2.75 b	6.19 a	9.69 a	7.66 a	4.41 ab	0.94 b	1.34 b	6.89 a	6.88 ab	4.13 ab
Lannate	1.10 kg/ha	0.50 c	1.25 b	7.09 ab	9.09 a	3.78 ab	0.13 b	0.50 b	2.86 b	5.72 ab	4.63 ab
Ammo	0.30 l/ha	0.25 c	0.31 b	2.81 bc	8.72 a	4.16 ab	0.09 b	0.22 b	2.80 b	7.47 ab	6.69 ab
Thiodan	3.00 l/ha	0.09 c	0.09 c	0.50 c	1.16 b	1.41 b	0.06 b	0.13 b	1.57 b	1.75 c	3.19 b
Ambush	0.90 l/ha	0.16 c	0.44 bc	6.53 ab	8.59 a	8.28 a	0.13 b	0.19 b	5.97 a	10.72 a	10.41 a
Mustang	42.00 g/ha	0.06 c	0.59 bc	3.78 bc	8.06 a	4.28 ab	0.03 b	0.13 b	1.56 b	5.47 ab	5.78 ab
Mustang	50.00 g/ha	0.13 c	0.44 bc	2.81 bc	6.53 a	6.28 a	0.16 b	0.25 b	2.59 b	9.03 a	6.66 ab
Agenda	56.00 g/ha	0.72 c	0.84 bc	4.66 bc	5.47 a	7.34 a	0.06 b	0.28 b	2.05 b	2.91 bc	5.38 ab

[a]Means within a column followed by the same letter are not significantly different (P=0.05) by SNK test. Means based on 6 cabbage plants per plot for 4 replications.

The above results showed, in both years of the study, that western cabbage flea beetle could be controlled effectively by Thiodan. Thiodan (endosulfan) acts as a contact and stomach poison. It is a versatile insecticide for the control of a broad spectrum of chewing, boring and sucking insect pests and some mite species in a wide variety of agricultural and horticultural crops. Results show that Thiodan can be used to effectively manage the western cabbage flea beetle in crucifer crops. Asana, a pyrethroid insecticide that offers broad-spectrum insect control across a wide range of crops, showed zero flea beetles per plant right after the initial application, thus it can be used for rapid response to reduce pest infestation particularly during outbreaks. Thiodan has a potential advantage over other insecticides for control of western cabbage flea beetle by providing longer periods of protection.

Repellent Efficacy Trials

In the 1996 repellent trials (Table 5.3), all repellents tested provided some suppression of flea beetles. Margosan-O-treated plots had significantly lower flea beetles (0 beetles per plant) among treatments in the 21 June (1 DAT) sample (F=5.54, P=0.0092). SunSpray-treated plots had significantly lower flea beetles among treatments on the 30 May (1 DAT), 24 June (4 DAT), and 1 July (11 DAT) sampling dates (F=3.70, P=0.0357; F=17.47, P=0.0001; F=3.97, P=0.0288, respectively). Both Margosan-O- and SunSpray-treated plots had a significantly lower number of beetles for treatments on 3 June (1 DAT) and 6 June (3 DAT) sampling dates (F=9.11, P=0.0011; F=4.48, P=0.0150, respectively).

Table 5.3. Mean number of flea beetles per plant observed on broccoli plants receiving foliar application of various repellents, Colorado State University Horticulture Field Research Center, Fort Collins, Colorado, 1996.

Treatment	Rate	Mean number of Flea Beetles / plant[a]									
		21-Jun (1 DAT)	30-May (1 DAT)	3-Jun (1 DAT)	6-Jun (3 DAT)	11-Jun (8 DAT)	20-Jun (1 DAT)	24-Jun (4 DAT)	28-Jun (8 DAT)	1-Jul (11 DAT)	11-Jul (21 DAT)
SunSpray	2% v:v	0.50 a	1.33 b	1.67 b	1.79 b	13.79 a	0.96 c	2.04 b	5.08 a	3.29 b	1.29 a
Guardian	10% v:v	0.29 a	2.00 ab	6.00 a	4.79 a	16.63 a	6.92 b	14.67 a	8.38 a	5.33 a	1.92 a
Margosan-O	1:150 v:v	0.00 b	2.17 ab	0.88 b	1.88 b	14.21 a	1.17 c	11.63 a	7.46 a	5.71 a	1.17 a
Water Check		0.50 a	3.92 a	5.58 a	3.96 ab	15.54 a	10.67 a	12.21 a	9.08 a	6.75 a	1.63 a

[a]Means within a column followed by the same letter are not significantly different (P=0.05) by SNK test. Means based on 4 plants per plot for 4 replications.

Margosan-O and SunSpray showed promise as repellents to lower flea beetle infestation. Guardian (garlic derivative), which only showed significant reduction compared to control on one day (20 June), was the least satisfactory among all the treatments.

In the 1997 repellent efficacy trials (Table 5.4), all treatments tested again provided some suppression of flea beetles. Azatin-treated plots had significantly lower number of flea beetles compared to the others on 5 June (1 DAT), 7 June (3 DAT), and 23 June (6 DAT) sampling dates (F=8.72, P=0.0015; F=6.07, P=0.0066; F=3.73, P=0.0340, respectively). Trilogy- and garlic-treated plots showed some significant effect in suppressing flea beetles. SunSpray, in contrast with the previous years finding, was least effective in repelling flea beetles.

In the 1998 repellent efficacy trails, treatments tested showed diverse results. In the first trial (Table 5.5), there was some significant reduction in the number of flea beetles among treatments. In 11 June (1 DAT) sample, the number of flea beetles per plant in plots treated with Jungle Rain were significantly lower compared to other treatments (F=5.97, P=0.0070). Azatin-treated plots also showed a significant reduction in flea beetle densities among treatments in the 1 July (6 DAT) sample (F=3.21, P=0.0523). No phytotoxicity was observed on any treated plant.

In the second trial (Table 5.6), none of the treatments tested showed a significant effect (P>0.05) in reducing flea beetle density on any sampling date. In the third trial (Table 5.7), some of the repellent-treated plots showed a lower number of flea beetles as compared to the untreated plots. Diatomaceous earth dust was significantly effective in reducing flea beetle densities on the 30 June (1 DAT) and 1 July (3 DAT) sampling dates

(F=6.12, P=0.0006; F=9.51, P=0.0001, respectively). Phytotoxic injury did occur on broccoli plants in the sandalwood oil-treated plots.

Results of repellent evaluations suggest that Margosan-O, SunSpray, Azatin and diatomaceous earth have potential to control *P. pusilla*. Flea beetles observed on plants treated with Margosan-O reached zero beetles per plant following the first application, and control was maintained up to eight days post treatment in the 1996 trial. SunSpray showed a similar effect in the 1996 trial but not in the 1997 trial. Both Margosan-O and SunSpray have oil in them causing the beetles to suffocate as they have been sprayed or causing treated leaves to become less attractive to flea beetles. Margosan-O has, in addition, a low concentration of azadirachtin; its antifeedant characteristics may have made this product more effective in repelling the beetles. Azatin has a higher concentration of azadirachtin, producing repellancy or death after ingestion of the sprayed formulation. Diatomaceous earth acts as a desiccant dust and possibly as an irritant making leaf surfaces unattractive to feeding.

Table 5.4. Mean number of flea beetles per plant observed on broccoli plants receiving foliar application of various repellents, Colorado State University Horticulture Field Research Center, Fort Collins, Colorado, 1997.

Treatment / Rate	Mean number of Flea Beetles / plant[a]												
	5-Jun (1DAT)	6-Jun (2 DAT)	7-Jun (3 DAT)	10-Jun (6 DAT)	11-Jun (1 DAT)	13-Jun (3 DAT)	17-Jun (7 DAT)	18-Jun (1 DAT)	20-Jun (3 DAT)	23-Jun (6 DAT)	28-Jun (1 DAT)	30-Jun (3 DAT)	4-Jul (7 DAT)
SunSpray / 2% v:v	3.40 ab	5.25 a	6.20 a	5.90 a	8.30 b	9.05 a	11.15 a	14.50 a	18.95 b	19.60 ab	12.35 a	22.55 b	13.00 b
Guardian / 10% v:v	3.45 ab	4.45 a	6.55 a	6.05 a	13.05 a	9.00 a	12.10 a	16.25 a	17.70 b	19.10 ab	7.35 b	12.90 c	6.75 c
Azatin / 2.5%	1.00 c	1.00 a	1.60 b	6.55 a	8.25 a	9.05 a	16.40 a	16.45 a	19.95 b	16.50 b	3.25 c	11.05 c	8.10 bc
Trilogy / 2% v:v	1.90 bc	3.2 a	4.80 a	7.35 a	7.75 b	7.35 a	13.60 a	11.45 a	25.45 a	23.15 a	4.05 c	40.10 a	20.80 a
UTC Water	5.80 a	4.6 a	6.00 a	8.65 a	17.65 a	8.7 a	13.75 a	16.85 a	21.20 ab	24.30 a	10.80 a	13.60 c	6.85 c

[a]Means within a column followed by the same letter are not significantly different (*P*=0.05) by SNK test. Means based on 5 plants per plot for 4 replications.

Table 5.5. Mean number of flea beetles per plant observed on broccoli plants receiving foliar application of various repellents, Colorado State University Horticulture Field Research Center, Fort Collins, Colorado, 1998.

Treatment	Rate	Mean number of Flea Beetles / plant[a]									
		1-Jun (4 DAT)	3-Jun (1 DAT)	10-Jun (8 DAT)	11-Jun (1 DAT)	15-Jun (5 DAT)	19-Jun (9 DAT)	26-Jun (1 DAT)	30-Jun (4 DAT)	1-Jul (6 DAT)	6-Jul (11 DAT)
Untreated Check		2.40 a	0.70 a	4.70 a	6.70 a	12.35 a	8.45 a	7.10 b	6.15 a	6.95 ab	9.45 a
Azatin	1:800 v:v	1.70 a	0.70 a	6.95 a	7.15 a	16.40 a	10.45 a	5.50 b	6.55 a	5.35 b	9.30 a
Hot Pepper	1: 32 v:v	1.75 a	0.35 a	6.60 a	4.45 ab	12.45 a	10.50 a	7.40 b	9.70 a	8.65 ab	10.50 a
Jungle Rain	1: 16 v:v	2.80 a	0.40 a	5.05 a	3.35 b	10.00 a	9.30 a	6.40 b	14.15 a	8.30 ab	8.30 a
SunSpray	1: 50 v:v	1.90 a	0.75 a	7.15 a	8.30 a	12.90 a	10.85 a	14.55 a	14.05 a	9.40 a	13.65 a

[a]Original data: data log transformed before analysis. Means within a column followed by the same letter are not significantly different (P=0.05) by SNK test. Means based on 5 cabbage plants per plot for 4 replications.

Table 5.6. Mean number of flea beetles per plant observed on broccoli plants receiving foliar application of various repellents in the field, Colorado State University Horticulture Field Research Center, Fort Collins, Colorado, 1998.

Treatment	Rate	Mean number of Flea Beetles / plant[a]		
		11-Jun (1 DAT)	15-Jun (5 DAT)	19-Jun (9 DAT)
Untreated Check		7.20 a	5.60 a	6.85 a
Azatin	1:800 v:v	5.85 a	5.35 a	7.45 a
BioNeem	1: 40 v:v	6.70 a	7.20 a	8.55 a
Guardian	1: 10 v:v	7.95 a	6.60 a	9.25 a
Hot Pepper	1: 32 v:v	4.80 a	7.10 a	8.80 a
Jungle Rain	1: 16 v:v	4.65 a	6.35 a	7.85 a
Sulfur	Dust	4.60 a	3.95 a	7.40 a
SunSpray	1: 50 v:v	7.90 a	6.65 a	9.50 a

[a]Means within a column followed by the same letter are not significantly different (P=0.05) by SNK test. Means based on 5 cabbage plants per plot for 4 replications.

Table 5.7. Mean number of flea beetles per plant observed on broccoli plants receiving foliar application of various repellents in the field, Colorado State University Horticulture Field Research Center in Fort Collins, Colorado, 1998.

Treatments	Rate	Mean number of Flea Beetles / plant[a]			
		30-Jun (1 DAT)	1-Jul (3 DAT)	6-Jul (8 DAT)	10-Jul (12 DAT)
Untreated Check		6.60 a	5.45 ab	4.60 a	2.20 a
BioNeem	1: 40 v:v	6.50 a	6.65 a	3.80 a	2.75 a
Clove Bud	5:800 v:v	6.95 a	6.40 a	5.55 a	3.25 a
Diatomaceous Earth	Dust	0.15 b	0.05 c	3.65 a	1.35 a
Guardian	1: 10 v:v	6.45 a	4.10 ab	3.05 a	1.50 a
Sage	5:800 v:v	6.45 a	7.35 a	5.45 a	3.10 a
Sulfur	3:800 v:v	6.35 a	4.80 ab	2.90 a	2.00 a
Sandalwood	5:800 v:v	4.90 a	2.75 b	3.00 a	1.40 a

[a]Means within a column followed by the same letter are not significantly different (P=0.05) by SNK test. Means based on 5 cabbage plants per plot for 4 replications.

The results of the present study reveal that some insecticides and repellents tested in the field show efficacy in control of western cabbage flea beetle adults. This study indicated that Thiodan and Asana were considerably more effective at controlling *P. pusilla* population than Provado, Sevin, Fipronil, Warrior, Mustang, Agenda, Ambush, Ammo, and Lannate. Although we did not test for flea beetle repellency and mortality on the above insecticides, a reduction in beetle counts on plants treated with Thiodan and Asana is an indication of either antifeedant or repellency effects, mortality effects, or both.

Repellency or mortality effects or both may also be attributed to the reduced flea beetle numbers on plants treated with Margosan-O, SunSpray, Azatin, and diatomaceous earth. Margosan-O and Azatin, formulations including neem's active ingredient azadirachtin, have antifeedant effects that deter the insect from feeding on the sprayed foliage. The flea beetle, *P. cruciferae*, has been found to feed less on plants treated with Margosan-O (Palaniswamy and Wise 1994). The antifeedant effects of azadirachtin on insects are well documented (see reviews by Jacobson 1989, Schmutterer 1990, Ascher 1993, Mordue and Blackwell 1993). The effect of azadirachtin might also be lethal. Neem extract formulations cause mortality in several insect species when ingested (Mikolajczak et al. 1989). Karel (1987) reported that application of neem extract formulations causes adult mortality in other chrysomelid insects as a result of feeding on treated plants or of the regimen leading to starvation. The reduction in flea beetles on plants treated with SunSpray and diatomaceous earth may also be attributed to mortality or repellency effects. SunSpray may kill the beetles by smothering them and/or repel them by changing the leaf surface making it unacceptable. Diatomaceous earth is a super-fine dust that can kill the insects by abrasion and dehydration or repel them by altering leaf surfaces.

When applying insecticides for control of flea beetles, extreme care must be taken in selecting the application dosage in order to save the non-target and beneficial organisms co-existing with *P. pusilla* in brassica plantings. It is also essential to determine the effects of prolonged applications of pesticides on the resistance capacity of *P. pusilla*. Insecticide resistance can increase the complexity of any insect control. In Manitoba, Canada, where granular insecticides have been more heavily used, the flea beetle, *P. cruciferae* has developed resistance to some insecticides (Palaniswamy and Wise 1994). With the possible development of pesticide resistance in *P. pusilla*, other control measures that protect plants from the pest are needed. The use of repellents or deterrents should result in slower resistance development in flea beetles.

It can be concluded from the present study that the adult stage of western cabbage flea beetle, *P. pusilla*, could be controlled by the application of Asana for rapid action or by Thiodan for prolonged action for up to two weeks. Certain repellents, including Margosan-O, SunSpray, Azatin and diatomaceous earth also showed a promise in reducing flea beetle infestation. Such repellents may be effective alternatives to conventional synthetic insecticides for the control of *P. pusilla*.

CITED REFERENCES

Abdul Kareem, A., R. C. Saxena, M. E. M. Boncodin, V. Krishnasamy, and D. V. Seshu. 1989. Neem as a seed treatment for rice before sowing on two homopterous insects and seedling vigor. J. Econ. Entomol. 82: 1219-1223.

Alford, D. V. 1977. Chemical control of the cabbage stem flea beetle, *Psylloides chrysocophala*, on winter oil-seed rape. Ann. Appl. Biol. 85: 369-374.

Ascher, K. R. S. 1993. Nonconventional insecticidal effects of pesticides available from the neem tree, *Azadirachta indica*, Arch. Insect Biochem. Physiol. 22: 433-449.

Black, I. A. and R. T. Hewson. 1984. Control of cabbage stem flea beetle and rape winter stem weevil on oilseed rape with deltamethrin. Asp. Appl. Biol. 293-297.

Chittenden, F. H. 1903. A brief account of the principal insect enemies of the sugar beet. U. S. Dept. Agr. Div. Ent. Bul. 43: 18-19.

Chittenden, F. H. and H. O. Marsh. 1920. The western cabbage flea beetle. USDA, Bulletin No. 902. 21 pp. Washington D.C.

Edelson, J. V., J. J. Magaro, and H. Browning. 1993. Control of insect pests on broccoli in southern Texas: a comparison between synthetic organic insecticides and biorational treatments. J. Entomol. Sci. 28: 191-196.

Ells, J. E, H. F. Schwartz, and W. S. Cranshaw. 1998a. Commercial broccoli. Colorado State Coop. Exten. Gardening Publication No. 7.622, 5 pp.

Ells, J. E, H. F. Schwartz, and W. S. Cranshaw. 1998b. Commercial cabbage. Colorado State Coop. Exten. Gardening Publication No. 7.618, 5 pp.

Ells, J. E, H. F. Schwartz, and W. S. Cranshaw. 1998c. Commercial cauliflower. Colorado State Coop. Exten. Gardening Publication No. 7.624, 5 pp.

Endersby, N. M. and W. C. Morgan. 1991. Alternatives to synthetic chemical insecticides for use in crucifer crops. Biol. Agric. and Hort. 8: 33-52.

Findlay, G. M. 1976. Field evaluation of insecticides for controlling flea beetles in rapeseed. Dept. Entomol. Univ. Manitoba, Winnipeg, Manitoba 45-47.

Frazier, J. L. 1986. The perception of plant allelochemicals that inhibit feeding. Pp. 1-42. *In* L. B. Brattsten and S. Ahmad (eds.), Molecular aspects of insect-plant associations. Plenum, New York.

Harris, G. R. and F. Gore. 1970. Laboratory tests on the contact toxicity of some insecticides to adults of the cabbage flea beetle, *Phyllotreta cruciferae*. J. Econ. Entomol. 63: 1025-1026.

Hough-Goldstein, J. and S. P. Hahn. 1992. Antifeedant and oviposition deterrent activity of an aqueous extract of *Tanacetum vulgare* L. on two cabbage pests. Environ. Entomol. 21: 837-844.

Howard, L. O. 1898. Injury by the western flea-beetle, *Phyllotreta pusilla* Horn. U. S. Dept. Agr. Div. Ent. Bul. 10: 92-93.

Jacobson, M. 1989. 1988 focus on phytochemical pesticides, volume 1: The Neem Tree. CRC Press, Boca Raton, FL. 178 pp.

Jermy, T. 1990. Prospects of antifeedant approach to pest control—a critical review. J. Chem. Ecol. 16: 3151-3166.

Karel, A. K. 1987. Response of *Ootheca bennigseni* (Coleoptera: Chrysomelidae) to neem extracts. Pp. 393-403. *In* H. Schmutterer and K. R. S. Ascher (eds.), Natural pesticides from the neem tree (*Azadirachta indica* A. Juss) and other tropical plants. Deutsche Gesellschaft fur Technische Zusammenarbeit (GTZ) Eschbor, Germany, 703 pp.

Lamb, R. J. 1980. Hairs protected pods of mustard (*Brassica hirta* 'Gisilba') from flea beetle feeding damage. Can. J. Plant Sci. 60: 1439-1440.

Lamb, R. J. 1984. Effects of flea beetles, *Phyllotreta* spp. (Chrysomelidae: Coleoptera), on the survival, growth, seed yield and quality of canola, rape and yellow mustard. Can. Entomol. 116: 269-280.

Lamb, R. J. 1989. Entomology of oilseed *Brassica* crops. Ann. Rev. Entomol. 34: 211-229.

Lamb, R. J., P. Palaniswamy, K. A. Pivnick, and M. A. H. Smith. 1993. A selection of oilseed rape, *Brassica rapa* L., with resistance to flea beetles, *Phyllotreta cruciferae* (Goeze) (Coleoptera: Chrysomelidae). Can. Entomol. 125: 703-713.

Meisner, J. and B. K. Mitchell. 1982. Phagodeterrent effect of neem extracts and azadirachtin on flea beetles, *Phyllotreta striolata* (F.). J. Plant Dis. Prot. 89: 463-467.

Mikolajczak, K. L., B. W. Zilkowski, and R. J. Bartlet. 1989. Effect of meliaceous seed extracts on growth and survival of *Spodoptera frugiperda* (J. E. Smith). J. Chem. Ecol. 15: 121-128.

Mordue, A. J. and A. Blackwell. 1993. Azadirachtin: an update. J. Insect Phys. 39: 903-924.

Munkvoid, G. P., D. C. McGee, and A. Iles. 1996. Effects of imidacloprid seed treatment of corn on foliar feeding and *Erwinia stewartii* transmission by the corn flea beetle. Plant. Dis. 80: 747-749.

Norris, D. M. 1986. Anti-feeding compounds. Pp. 99-146. *In* W. S. Bowers, W. Edbing, T. R. Fukuto, D. Martin, R. Wegler and I. Yamamoto (eds.), Chemistry of plant protection 1. Sterol biosynthesis, inhibitors, and anti-feeding compounds. Springer, New York.

Palaniswamy, P. and I. Wise. 1994. Effects of neem-based products on the number and feeding activity of a crucifer flea beetle, *Phyllotreta cruciferae* (Goeze) (Coleoptera: Chrysomelidae), on canola. J. Agric. Entomol. 11: 49-60.

Ratcliffe, R. H., L. P. Ditman, and J. T. Whitlaw, Jr. 1961. Field experiments on insecticidal control of insect pests of cabbage and broccoli. Izvestija na Balgarskoto Istoricesko Druzestvo. 54: 365-369.

Roos, U. P., and W. B. Tappan. 1972. Laboratory evaluation of six insecticides against the tobacco flea beetle. J. Econ. Entomol. 65: 217-219.

SAS Institute. 1985. SAS user's guide: Statistics, 5^{th} ed. SAS Institute, Cary, NC.

Saxena, R. C. 1987. Neem seed oil – a potential antifeedant against insect pests of rice. Pp. 139-144. *In* R. Greenhalgh and T. R. Roberts (eds.), Pesticide Science and Biotechnology. Blackwell Scientific Pub., Oxford, 604 pp.

Schmutterer, H. 1990. Properties and potential of natural pesticides from the Neem tree, *Azadirachta indica*. Ann. Rev. Entomol. 35: 271-297.

Schmutterer, H. and C. Hellpap. 1989. Effects of neem on pests of vegetables and fruit trees. Pp. 69-86. *In* M. Jacobson (ed.), Phytochemical Pesticides, vol. 1, The Neem Tree. CRC Press, Boca Raton, Florida, 178 pp.

Young, J. R. and L. P. Ditman. 1959. The effectiveness of some insecticides on several vegetable crops. Ibid. 52: 477-481.

CHAPTER VI

DEVELOPMENT OF ACTION THRESHOLDS FOR WESTERN CABBAGE FLEA BEETLE CONTROL

INTRODUCTION

The western cabbage flea beetle, *Phyllotreta pusilla* Horn (Chrysomelidae: Coleoptera), is a serious pest of seedling brassica crops (Brassicaceae) in the midwestern region of the United States (Chittenden and Marsh 1920). Brassica crops including broccoli, cabbage, and cauliflower are grown on approximately 3600 acres in Colorado (divided into 2000 acres for cabbage, 1300 acres for broccoli, and 300 acres for cauliflower) mainly in Adams, Weld, Delta, and Montrose counties (Ells et al., 1998abc).

Western cabbage flea beetles frequently attack newly emerged seedlings in spring, feeding mostly on the adaxial surface of cotyledons and leaves, creating pits that give the plants a "shot-holed" appearance. Beetles have three generations a year and feed on plants during the spring (April), early summer (June), mid-summer (late July), and during late summer (September), when the third generation of adults emerge to feed before hibernating. Adults overwinter under plant debris or clumps of earth or in the soil (Chittenden and Marsh 1920).

Stern et al. (1959) initiated the concept of economic injury level (EIL) raising concerns about excessive use of insecticides. The relationship between insect density or plant injury to crop yield loss can be used to establish an economic injury level, often considered the lowest insect population density that will cause economic damage (Metcalf and Metcalf 1993). The economic injury level is a criterion to indicate what insect density or plant injury level results in economic loss. Moreover, it is the basis for setting the economic threshold level, the level of pest populations at which control should be implemented to protect crops from economic loss (Metcalf and Metcalf 1993).

The term threshold, used and defined in integrated pest management (IPM), indicates the point at which some effect begins (i.e., damage or economic loss). In IPM, economic threshold is defined as the pest density, below the economic injury level, that warrants initiation of control strategy, usually insecticides (Metcalf and Metcalf 1993). Because the economic threshold is a general term that contains all three definitions of the threshold for economic damage (ED), the economic injury level (EIL) and the economic threshold (ET) it has been modified to the concept "action threshold" (Dent 1991). The action threshold concept, therefore, seems more understandable than economic threshold since it helps determine both the need for control actions and the proper timing of such actions.

No thresholds for controlling flea beetles are used in Colorado. Moreover, an action threshold has not been established for either the adults or larval stage of the western cabbage flea beetle. Current recommendations for flea beetle infestation are to spray on a regular basis or "when needed", but without regard to specific flea beetle densities. This practice can result in unnecessary applications of insecticides that cost the grower money and cause unneeded increase in the load of pesticides in the environment.

The relationship of flea beetle feeding injury to brassica crop yield losses has been studied by several researchers (Lamb 1984). It has been shown (Putnam 1977, Lamb and

Turnock 1982) that flea beetle damage to oilseed *Brassica* can reduce yield. The loss of yield results from a reduction of plant stand and the inability of plants to recover from damage that occurs soon after seedling emergence (Osgood 1975). It has been suggested by Putnam (1977) that flea beetle damage can reduce plant stand, delay maturity of plants, and stunt plants in later developmental stages.

Flea beetle adults, which are the most injurious stage, are very active, and the relative numbers of adults can be assessed by a standardized sweeping technique (Granovsky and Peterson 1954). However, this is very tedious, and a more common method is to count the number of feeding holes in the leaves. Thus, for potato flea beetles Wolfenbarger (1936) and Anderson and Walker (1934) counted the number of holes per leaflet, and Granovsky and Peterson (1954) counted the number of feeding holes per square inch of leaf.

The action threshold for the western cabbage flea beetle adults should be considered of primary importance for timing chemical control in brassica crop fields. Although little attention has been directed toward the possibility of loss caused by larval feeding injuries to the roots, two reports (Burgess 1977 and Westdal and Romanow 1972) have hypothesized that such losses may occur. The goal of this study was to determine if an action threshold could be determined that would allow control decisions to be made well before feeding damage by the western cabbage flea beetle reached the economic injury level and to establish an action threshold for western cabbage flea beetle attacking cultivars differing in their level of acceptance to the flea beetles.

METHODS AND MATERIALS

Action threshold trials were conducted at the Horticulture Field Research Center in Fort Collins, CO during the summer of 1997 and 1998. Plants for each trial were grown in the greenhouse for about four weeks prior to field transplanting. After transplanting into the field, plants were grown under standard husbandry practices and plots were kept weed free.

All experiments were conducted on populations of naturally occurring western cabbage flea beetle adults. Insecticides selected to keep flea beetles under selected action thresholds were applied using a CO_2 compressed air sprayer delivering 140 l/ha at 2.1 kg/cm in two passes directed along the sides of the planting. Plots for both trials were sampled weekly by visual inspection of leaf surface of a number of plants in the center of each plot. Inspection and counting of flea beetle adults was conducted using the "sneak-up" method described before. After sampling, a selected insecticide was applied to the appropriate plots that exceeded the pre-designated action threshold level for each plot.

In the 1997 action threshold trial, cabbage (cv. 'Hybrid Stonehead', W. Atlee Burpee & Co.) seedlings, at the third-leaf stage, were transplanted on 19 May in four-row plots (77-cm between rows) each with 16 plants per row in 38-cm in-row spacing in 6-m long plots. The first and last row in each plot served as untreated buffer rows, and they were not included in the test. Plots were replicated four times in a randomized complete block design. Monitoring of flea beetles was done by counting the number of flea beetle adults on ten plants from the center two rows of each plot once a week. An insecticide, lambda-cyhalothrin (Warrior®, FMC Corp.), was applied when thresholds of 0, 2, 5, or 10 flea beetle per plant were identified. Cabbage yield was measured on 8 August by taking the weight of ten heads per plot.

In the 1998 trial, an integration of plant resistance (based on the flea beetle preference studies identified in Chapter II) and action thresholds for flea beetle management were undertaken in the same site. Two cabbage cultivars, 'Copenhagen Market' (a more preferred cabbage variety for western cabbage flea beetles) and 'Red Acre' (a less preferred cabbage variety) (The Rocky Mountain Seed Co.) and two broccoli varieties, 'Premium Crop' (a less preferred broccoli variety) (The Rocky Mountain Seed Co.) and 'Green Goliath' (a more preferred broccoli variety) (Henry Field Seed & Nursery Co.) seedlings, at the third-leaf stage, were transplanted in separate rows (77-cm between rows). All varieties were transplanted on 27 May to 4.5-m plots each with 11 plants in a 41-cm in row spacing. Plots were replicated four times and designed in a randomized complete block design. Monitoring of flea beetles was done by counting the number of flea beetle adults on five plants from the center of each plot once a week. An insecticide, permethrin (BugStop®, Exxon Chemical Co.) was applied when the respective thresholds of 0, 2, 5, or 10 flea beetles per plant were identified. Prior to crop maturity, head measurement for each variety for both crops was taken two times. Yields for all cultivars were measured on 8 August by taking the weight of five heads per plot.

To examine the effects of different action thresholds on the size and weight of cabbage and broccoli heads, data were analyzed with two-way ANOVA (SAS institute 1985) testing for effects of treatments (action thresholds) and block. Analyses were carried out on the mean cabbage or broccoli head diameter and head weight per plant for each treatment for each block. Comparisons of the effect of action thresholds on cabbage or broccoli head size and weight were carried out using Student-Newman-Keuls (SNK) (SAS institute 1985).

RESULTS AND DISCUSSION

Four population levels of 0, 2, 5, and 10 flea beetle adults per plant were kept during the 1997 and 1998. To maintain these levels, different number of sprays were applied to each as the flea beetles reach the designated threshold. In the 1997 action threshold trial (Table 6.1), flea beetle populations attacking cabbage plants exceeded the pre-designated threshold levels of 0, 2, and 5-beetles per plant on 2 June. Those plots were treated on the same day to make the flea beetles numbers drop below the thresholds. The beetles did not reach the density of 10-beetles per plant until 17 June at which time these plots were sprayed. The 0-beetles per plant plots were sprayed on all sampling dates as a result of flea beetles exceeding the 0-beetles per plant level on every sampling date. The 2-beetles per plant plots were sprayed three times: 2, 11, and 24 June. The 5-beetles per plant plots were also sprayed three times on 2, 17, and 30 June. The 10-beetles per plant plots were only sprayed once, on 17 June.

Cabbage yields (Table 6.2) were significantly higher on the plots maintained at 0, 2, and 5-flea beetles per plant than on plots maintained at 10-beetles per plant (F=27.17, P=0.0001). As the number of flea beetles reached 10-beetles per plant, the cabbage head weight was significantly reduced (1100.4 grams per plant) as compared to 0, 2 or 5-beetles per plant (1775.80, 1626.9, and 1667.3 grams per plant, respectively). Although cabbage yields from plots maintained at 0, 2, and 5-beetles per plant were not significantly different, the level of flea beetle population at which yield was not affected and beyond which immediate insecticidal resulted in significant yield benefit was 5-beetles per plant.

Table 6.1. Seasonal population density of western cabbage flea beetles on cabbage managed in different action thresholds, Colorado State University Horticulture Field Research Center, Fort Collins, Colorado, 1997.

Threshold	Mean Number of Flea Beetles / Plant[ab]						
	2-Jun	6-Jun	11-Jun	17-Jun	24-Jun	30-Jun	9-Jul
0 Beetles/Plant	6.58	0.04	1.79	1.54	2.50	0.50	0.54
2 Beetles/Plant	4.33	0.13	2.58	1.58	10.92	0.63	1.63
5 Beetles/Plant	5.00	0.13	1.58	6.67	2.08	9.79	0.21
10 Beetles/Plant	4.90	5.17	8.33	13.29	5.08	8.46	3.46

[a]Means are based on 10 cabbage plants per plot for 4 replications.

[b]Cabbage flea beetles maintained at different levels by applying Warrior® (lambda-cyhalothrin) at the rate of 0.02 kg ai/ha.

Table 6.2. Cabbage yield in plots managed in different action threshold populations of western cabbage flea beetle on cabbage cultivar 'Hybrid Stonehead'. Colorado State University Horticulture Field Research Center, Fort Collins, Colorado, 1997.

Action Threshold	Cabbage Yield / Plant[ab]
0 Beetles/Plant	1775.8 a
2 Beetles/Plant	1626.9 a
5 Beetles/Plant	1667.3 a
10 Beetles/Plant	1100.4 b

[a]Means within a column followed by the same letter are no significantly different (P=0.05) by SNK test. Mean yield per plant (grams) is based on 10 cabbage heads per plot for 4 replications.

[b]Cabbage flea beetles maintained at different levels by applying Warrior® (lambda-cyhalothrin) at the rate of 0.02 kg ai/ha.

In the 1998 action threshold trials, plots with different action threshold levels in all cultivars received different number of insecticide applications. With the cabbage cultivar 'Copenhagen Market' (Table 6.3) plots with a 0-beetles per plant threshold received a weekly spray as the beetles constantly exceeded the 0 threshold. The 2 and 5-beetles per plant threshold plots received only two sprays throughout the season on 10 and 22 June, while the 10-beetles per plant threshold plots did not receive any insecticidal application.

Within the cabbage cultivar 'Red Acre' (Table 6.4), a variety previously found to be less preferred by the flea beetles, plots maintained with 2 and 5-beetles per plant threshold received a fewer number of applications than the more preferred cultivar 'Copenhagen Market'. Those plots received only a single application on the 10 June sampling date (Table 6.4). However, the number of applications for both 0 and 10-beetles per plant threshold plots were the same as for 'Copenhagen Market'.

Broccoli cultivars, 'Green Goliath', which is more preferred, and 'Premium Crop', which is less preferred, showed contrasting numbers of applications compared to the cabbage cultivars. 'Green Goliath' plots (Table 6.5) with a 0-beetles per plant threshold received weekly applications for a total of five applications. Plots with 2-beetles per plant threshold received two applications on 10 and 22 June. The 5 and 10-beetles per plant threshold plots received only a single application on 22 June and 30 June, respectively.

Table 6.3. Seasonal population density of western cabbage flea beetles on cabbage variety 'Copenhagen Market' managed in different action thresholds. Colorado State University Horticulture Field Research Center, Fort Collins, Colorado, 1998.

Action Threshold	Mean Number of Flea Beetles / Plant[ab]				
	3-Jun	10-Jun	16-Jun	22-Jun	30-Jun
Untreated Control	0.15	8.40	6.95	9.75	12.45
0 Beetles/Plant	0.05	1.55	0.05	1.25	1.10
2 Beetles/Plant	0.30	6.10	0.10	4.05	1.20
5 Beetles/Plant	0.35	5.80	0.65	5.35	0.65
10 Beetles/Plant	0.30	7.00	0.30	5.70	9.85

[a]Means are based on 5 cabbage plants per plot for 4 replications.

[b]Cabbage flea beetles maintained at different levels by applying BugStop® (permethrin) at the rate of 1:128 v:v.

Table 6.4. Seasonal population density of western cabbage flea beetles on cabbage variety 'Red Acre' managed in different action thresholds. Colorado State University Horticulture Field Research Center, Fort Collins, Colorado, 1998.

Action Threshold	Mean Number of Flea Beetles / Plant[ab]				
	3-Jun	10-Jun	16-Jun	22-Jun	30-Jun
Untreated Control	0.20	4.2	1.70	4.65	5.10
0 Beetles/Plant	0.15	1.00	0.25	0.65	0.60
2 Beetles/Plant	0.25	4.60	0.35	0.35	1.30
5 Beetles/Plant	0.25	6.40	0.40	2.30	1.30
10 Beetles/Plant	0.00	2.25	2.30	2.65	6.50

[a]Means are based on 5 cabbage plants per plot for 4 replications.

[b]Cabbage flea beetles maintained at different levels by applying BugStop® (permethrin) at the rate of 1:128 v:v.

Table 6.5. Seasonal population density of western cabbage flea beetles on broccoli variety 'Green Goliath' managed in different action thresholds. Colorado State University Horticulture Field Research Center, Fort Collins, Colorado, 1998.

Action Threshold	Mean Number of Flea Beetles / Plant[ab]				
	3-Jun	10-Jun	16-Jun	22-Jun	30-Jun
Untreated Control	0.15	6.20	3.95	6.20	9.70
0 Beetles/Plant	0.20	0.15	0.15	3.90	1.80
2 Beetles/Plant	0.45	4.04	0.40	3.10	0.85
5 Beetles/Plant	0.45	4.75	0.40	6.35	0.60
10 Beetles/Plant	0.40	4.80	2.65	4.75	10.50

[a]Means are based on 5 broccoli plants per plot for 4 replications.

[b]Cabbage flea beetles maintained at different levels by applying BugStop® (permethrin) at the rate of 1:128 v:v.

'Premium Crop' (Table 6.6) plots with 0, 2 and 10-beetles per plant thresholds received the same number of applications as 'Green Goliath' plots. However, 'Premium Crop', which is supposedly less preferred by the beetles, received a higher number of applications in the 5-beetles per plant threshold plots than 'Green Goliath'. Plots with 5-beetles per plant threshold received two applications on 10 and 22 June.

Both cabbage cultivars, 'Red Acre' and 'Copenhagen Market', showed significant differences in head diameter on both measurement dates (Tables 6.7, 6.8). With 'Red Acre' (Table 6.7) on the 21 July measurement date 0-beetle per plant plots showed significantly larger heads than those from the control plots and from the plots maintained at 10-beetles per plant (F=5.59, P=0.0089). There were no significant differences in head sizes between 0, 2, and 5-beetles per plant plots, and between the 2, 5, and 10-beetles per plant plots. There also were no significant differences in head size between the 10-beetles per plant and the control plots.

On the 30 July measurement date for 'Red Acre', plots maintained at 0, 2, and 5-beetles per plant thresholds were not significantly different in head size, and each had significantly larger head sizes than the 10-beetles per plant threshold plots and the controls (F=9.46, P=0.0011). Similarly on the 21 July date, head size from plots maintained at 10-beetles per plant and from controls had no significant differences. On the two sampling dates, the head size of the cabbage cultivar 'Red Acre' in the 10-beetles per plant threshold and the control plots, which neither received any insecticidal application, had been similarly affected by flea beetle feeding damage.

Table 6.6. Seasonal population density of western cabbage flea beetles on broccoli variety 'Premium Crop' managed in different action thresholds. Colorado State University Horticulture Field Research Center, Fort Collins, Colorado, 1998.

Action Threshold	Mean Number of Flea Beetles / Plant[ab]				
	3-Jun	10-Jun	16-Jun	22-Jun	30-Jun
Untreated Control	0.40	9.55	4.75	9.60	17.55
0 Beetles/Plant	0.25	0.75	0.30	3.10	4.10
2 Beetles/Plant	0.50	8.05	0.80	4.20	0.85
5 Beetles/Plant	0.60	9.40	0.05	9.00	1.40
10 Beetles/Plant	0.40	8.95	0.40	8.55	15.75

[a]Means are based on 5 broccoli plants per plot for 4 replications.

[b]Cabbage flea beetles maintained at different levels by applying BugStop® (permethrin) at the rate of 1:128 v:v.

Table 6.7. Head Diameter of cabbage (cv. 'Red Acre') in plots managed in different action threshold populations of western cabbage flea beetle. Colorado State University Horticulture Field Research Center, Fort Collins, Colorado, 1998.

Action Threshold	Mean Head Diameter (cm) / Plant[ab]	
	21-Jul	30-Jul
0-Beetles/Plant	4.73 a	7.15 a
2-Beetles/Plant	3.35 abc	6.30 a
5-Beetles/Plant	4.08 ab	5.83 a
10-Beetles/Plant	2.68 bc	4.23 b
Untreated Control	2.30 c	3.40 b

[a]Means within a column followed by the same letter are no significantly different (P=0.05) by SNK test. Mean head diameter per plant (cm) is based on 10 cabbage heads per plot for 4 replications.

[b]Cabbage flea beetles maintained at different levels by applying BugStop® (permethrin) at the rate of 1:128 v:v.

The head diameter measurement of the cultivar 'Copenhagen Market' (Table 6.8) showed significant differences in head size on both measurement dates. On the 21 July sampling date, head sizes measured in plots maintained at 0, 2, 5, and 10-beetles per plant thresholds showed no significant differences between them, and all had significantly larger heads than the control (F=6.72, P=0.0045). On the 30 July measurement date, the 0-beetles per plant plots had significantly larger head sizes than the 10-beetles per plant plots and than the control plots (F=17.86, P=0.0001). There were also significant differences between head size from the 10-beetles per plant plots and the control plots.

Head measurement for the broccoli cultivars 'Green Goliath' and 'Premium Crop', showed significant differences in head sizes on both measurement dates. Head sizes for 'Green Goliath' (Table 6.9) were significantly larger in the 0, 2, and 5-beetles per plant plots than in the 10-beetles per plant plots and the control (F=6.89, P=0.0040, F=9.52, P=0.0011, respectively). Also, head sizes in the 10-beetles per plant threshold plots were not significantly different from those in the control plots. Even though the 10-beetles per plant plots received a single insecticidal application, flea beetle effects on the growth of broccoli heads were the same as in the control plots.

Table 6.8. Head Diameter of cabbage (cv. 'Copenhagen Market') in plots managed in different action threshold populations of western cabbage flea beetle. Colorado State University Horticulture Field Research Center, Fort Collins, Colorado, 1998.

Action Threshold	Mean Head Diameter (cm) / Plant[ab]	
	21-Jul	30-Jul
0-Beetles/Plant	9.33 a	14.65 a
2-Beetles/Plant	7.65 a	12.55 ab
5-Beetles/Plant	8.43 a	13.12 ab
10-Beetles/Plant	7.80 a	11.33 b
Untreated Control	5.73 b	8.28 c

[a]Means within a column followed by the same letter are no significantly different (P=0.05) by SNK test. Mean head diameter per plant (cm) is based on 10 cabbage heads per plot for 4 replications.

[b]Cabbage flea beetles maintained at different levels by applying BugStop® (permethrin) at the rate of 1:128 v:v.

Table 6.9. Head Diameter of broccoli (cv. 'Green Goliath') in plots managed in different action threshold populations of western cabbage flea beetle. Colorado State University Horticulture Field Research Center, Fort Collins, Colorado, 1998.

Action Threshold	Mean Head Diameter (cm) / Plant[ab]	
	21-Jul	30-Jul
0-Beetles/Plant	8.25 a	18.60 a
2-Beetles/Plant	6.05 a	16.63 a
5-Beetles/Plant	5.90 a	13.98 a
10-Beetles/Plant	2.30 b	6.75 b
Untreated Control	1.58 b	5.65 b

[a]Means within a column followed by the same letter are no significantly different (P=0.05) by SNK test. Mean head diameter per plant (cm) is based on 10 broccoli heads per plot for 4 replications.

[b]Cabbage flea beetles maintained at different levels by applying BugStop® (permethrin) at the rate of 1:128 v:v.

Head size in the broccoli cultivar 'Premium Crop' was significantly different among treatments on both measurement dates (Table 6.10). The head sizes measured on the 21 July were significantly larger in the 0-beetle/plant plots than in the control and the 2, 5, and 10-beetles per plant plots (F=7.99, P=0.0022). The head sizes in the 2, 5, and 10-beetles per plant plots were also significantly larger than the heads in the control plots. Similarly, the head sizes on the 30 July measurement date were significantly larger in the 0-beetles per plant plots than heads in the 2, 5, and 10-beetles per plant plots and in the control (F=12.68, F=0.0003). The head sizes in the 2 and 5-beetles per plant plots were significantly larger than in the control plots. The head sizes in the 10-beetles per plant plots and in the control plots, however, were not significantly different.

Cabbage and broccoli yields obtained from plots maintained at different levels of action thresholds of flea beetle differed substantially among cultivars (Table 6.11). Almost all the treated plots, except the 10-beetles per plant plots, in all the varieties tested gave significantly higher yield than was produced on control plots. Yield obtained from the cabbage cultivar 'Copenhagen Market' plots was generally greater than that obtained from the 'Red Acre' plots. Similarly, yield obtained from the broccoli cultivar 'Green Goliath' plots was generally greater than that obtained from the 'Premium Crop' plots (Table 6.11)

With the cabbage cultivar 'Copenhagen Market', yields obtained from plots maintained at different thresholds were significantly greater than the control (Table 6.11) (F=20.61, P=0.0001). Moreover, plots maintained at the 0-beetles per plant threshold had significantly greater yield than the 2 and 10-beetles per plant threshold plots and than the control plots. However, yields in the 0 and 5-beetles per plant as well as in the 2 and 10-

beetles per plant thresholds showed no significant differences. With the cabbage cultivar 'Red Acre' yield obtained from plots maintained at 0-beetles per plant was significantly greater among all other action thresholds including the control (F=14.71, P=0.0001). However, yield from plots maintained at 2 and 5-beetles per plant and showed no significant differences between them, and yield from plots maintained at 2 and 10-beetles per plant was not significantly different from the control.

Yields obtained from broccoli ('Green Goliath') plots maintained at different action thresholds showed significant differences between treatments (Table 6.11) (F=10.73, P=0.0006). Yields obtained from plots maintained at 0, 2, and 5-beetles per plant threshold were significantly greater than from the 10-beetles per plant threshold and the control plots. However, the 10-beetles per plant threshold plots showed no significant differences in yield compared to the control plots. In the broccoli cultivar 'Premium Crop', the only plot that gave significantly greater yield was the one maintained at 0-beetles per plant threshold plot (Table 6.11) (F=7.31, P=0.0031). The other threshold plots gave yields that were not significantly different from the control.

Table 6.10. Head Diameter of broccoli (cv. 'Premium Crop') in plots managed in different action threshold populations of western cabbage flea beetle. Colorado State University Horticulture Field Research Center, Fort Collins, Colorado, 1998.

Action Threshold	Mean Head Diameter (cm) / Plant[ab]	
	21-Jul	30-Jul
0-Beetles/Plant	3.28 a	11.63 a
2-Beetles/Plant	1.93 b	7.50 b
5-Beetles/Plant	2.00 b	7.45 b
10-Beetles/Plant	1.60 b	5.33 bc
Untreated Control	0.80 c	3.13 c

[a]Means within a column followed by the same letter are no significantly different (P=0.05) by SNK test. Mean head diameter per plant (cm) is based on 10 broccoli heads per plot for 4 replications.

[b]Cabbage flea beetles maintained at different levels by applying BugStop® (permethrin) at the rate of 1:128 v:v.

Table 6.11. Yield in plots managed in different action threshold populations of western cabbage flea beetle on cabbage and broccoli cultivars. Colorado State University Horticulture Field Research Center, Fort Collins, Colorado, 1997.

Action Threshold	Yield / Plant[ab]			
	Red Acre	Copenhagen Market	Green Goliath	Premium Crop
0-Beetles/Plant	1727.40 a	1946.00 a	680.81 a	560.00 a
2-Beetles/Plant	1108.00 bc	1478.70 bc	653.07 a	297.12 b
5-Beetles/Plant	1316.10 b	1715.20 ab	502.47 a	298.12 b
10-Beetles/Plant	859.10 c	1316.40 c	238.52 b	230.84 b
Untreated Control	771.10 c	903.50 d	278.65 b	263.25 b

[a]Means within a column followed by the same letter are no significantly different (*P*=0.05) by SNK test. Mean yield per plant (grams) is based on 10 heads per plot for 4 replications.

[b]Cabbage flea beetles maintained at different levels by applying BugStop® (permethrin) at the rate of 1:128 v:v.

Western cabbage flea beetle feeding damage has substantial effects on cabbage and broccoli plants causing difference in size and weight of growing heads. Differences among treatments discussed above can be attributed to the level of flea beetle density and subsequent damage. Size and weight of cabbage and broccoli heads was directly related to the number of insecticide applications. The largest and heaviest heads were in those plots that received multiple insecticide applications (i.e., the 0 and 5-beetles per plant threshold plots); vice versa, the smallest and lightest heads were in those plots that did not receive any application (i.e., the control and sometimes the 10-beetles per plant threshold plots). The 1998 action threshold data suggest that yield (=head weight) is more sensitive than head diameter.

Differences among cabbage and broccoli cultivars in size and weight of heads can not totally be attributed to the flea beetle damage because some differences in growth and yield would occur in the absence of damage. Lamb (1984) found differences in growth rate, plant height, yield, and seed size between canola, *Brassica napus* L., and yellow mustard, *Sinapis alba* L. It is evident, however, that differences in susceptibility of the different crops and cultivars to flea beetle damage had a large impact on their performance under the different levels of infestation.

The different thresholds of this study were designed to produce different levels of damage to determine a threshold where damage affected yields and, thus, the time at which management action should be utilized to effect economic return. From the 1997 and 1998 action threshold studies, great yield losses occurred at the action threshold of 10-beetles per plant. This suggests that the threshold level of flea beetles that will cause economic loss is a density between 5 and 10-beetles per plant. Thus, the action threshold that should be utilized to prevent flea beetle damage to crop should be somewhat below the 10-beetles per plant density. Since differences were mostly marginal in the lower levels (the thresholds of 0 through 5 flea beetles per plant), the 5 flea beetle per plant threshold, therefore, appears to be an appropriate action threshold for flea beetle control on seedling brassica crops. Cabbage and broccoli cultivar differences in susceptibility to flea beetles injury and seasonal intensity of flea beetles infestation may modify this. The adoption of such a threshold should result in significantly less need for insecticide applications on brassica crops than occurs at present.

REFERENCES CITED

Anderson, L. C. and H. G. Walker. 1934. The life history and control of the potato flea beetle, *Epitrix cucumeris* Harris on the Eastern Shore of Virginia. J. Econ. Entomol. 27: 102-106.

Burgess, L. 1977. Flea beetles (Coleoptera: Chrysomelidae) attacking rape crops in the Canadian prairie provinces. Can. Entomol. 109: 21-32.

Chittenden, F. H. and H. O. Marsh. 1920. The western cabbage flea beetle. USDA, Bulletin No. 902. 21 pp. Washington D.C.

Dent, D. 1991. Insect Pest Management. Redwood Press Ltd, Wiltshire, United Kingdom. 604 pp.

Ells, J. E., H. F. Schwartz, and W. S. Cranshaw. 1998a. Commercial broccoli. Colorado State Coop. Exten. Gardening Publication No. 7.622, 5 pp.

Ells, J. E., H. F. Schwartz, and W. S. Cranshaw. 1998b. Commercial cabbage. Colorado State Coop. Exten. Gardening Publication No. 7.618, 5 pp.

Ells, J. E., H. F. Schwartz, and W. S. Cranshaw. 1998c. Commercial cauliflower. Colorado State Coop. Exten. Gardening Publication No. 7.624, 5 pp.

Granovsky, A. A. and A. G. Peterson. 1954. Evaluation of potato leaf injury caused by leafhoppers, flea beetles and early blight. J. Econ. Entomol. 47: 894-901.

Lamb, R. J. 1984. Effects of flea beetles, *Phyllotreta* spp. (Chrysomelidae: Coleoptera), on the survival, growth, seed yield and quality of canola, rape and yellow mustard. Can. Entomol. 116: 269-280.

Lamb. R. J. and W. J. Turnock. 1982. Economics of insecticidal control of flea beetles (Coleoptera: Chrysomelidae) attacking rape in Canada. Can. Entomol. 114: 827-840.

Metcalf, L. M. and R. A. Metcalf. 1993. Destructive and Useful Insects: Their Habits and Control. McGraw Hill. New York. 981 pp.

Osgood, C. E. 1975. Damage assessment as part of flea beetle management on rape. Rep. Agric. Pesticide Soc. 1975: 54-55.

Putnam, L. G. 1977. Response of four brassica seed crop species to attack by the crucifer flea beetle, *Phyllotreta cruciferae*. Can. J. Plant Sci. 57: 987-989.

SAS Institute. 1985. SAS user's guide: Statistics, 5th ed. SAS Institute, Cary, NC.

Stern, V. M., R. F. Smith, R. van den Bosch and K. S. Hagen. 1959. The integrated control concept. Hilgardia 29: 81-101.

Westdal, P. H. and W. Romanow. 1972. Observation on the biology of the flea beetle, *Phyllotreta cruciferae* (Coleoptera: Chrysomelidae). Man. Entomol. 6: 35-45.

Wolfenbarger, D. O. 1936. Insect and disease evaluation in potato experiments. J. Econ. Entomol. 29: 187-189.

SUMMARY

This project was developed to investigate different management tactics for the western cabbage flea beetle, *Phyllotreta pusilla* Horn. The management tactics investigated were host plant preference, planting density, interplanting, trapping, application of different insecticides and repellents, and chemical management using action thresholds.

In the host plant preference study, Chinese cabbage sustained higher flea beetle density in the field than the other brassica crops. Chinese cabbage also was more preferred in the laboratory choice tests than the other crops tested. Cauliflower, Brussels sprouts and cabbage were less preferred by flea beetles in the field tests, and Brussels sprouts, cauliflower, broccoli, collard and kale were less preferred in the laboratory choice tests.

Among the cabbage cultivars tested, 'Golden Acre' and 'Copenhagen Market' were most preferred, and 'Red Acre' 'Earliana' and 'Salad Delight' were least preferred. Among the broccoli cultivars, 'Green Goliath' was more preferred than 'Love Me Tender Hybrid' and 'Premium Crop'.

In the planting density study, increased plant density resulted in a significant decrease in flea beetles infesting individual broccoli plants but in an increase in total number of flea beetles within the area of increased plant density. The number of flea beetles colonizing all broccoli plants in an area was significantly lower in the 40-cm in-row spacing plant density compared to 5, 10, and 20-cm in-row spacing plant density. The number of flea beetles colonizing individual broccoli plants in an area was significantly

higher in 40-cm in-row spacing plant density compared to 5, 10, and 20-cm in-row spacing density.

In interplanting trials, greater flea beetle densities were found on broccoli in plots with no radishes. In the 1997 trial, broccoli plants interplanted with radishes in 15-cm and in 30-cm in-row spacing had significantly lower flea beetle infestation than the control. In the 1998 trial, broccoli plants interplanted with radishes in 5-cm and 10-cm in-row spacing had significantly lower number of flea beetles than the control. Interplanting broccoli with radishes did not significantly change head weight and the subsequent yield of broccoli plants compared with a sole crop of broccoli.

Field and laboratory evaluations of radish cultivars that may work best as diversionary crops to attract flea beetles away from broccoli plants showed that Chinese Daikon and Black Spanish had the highest flea beetle infestation among other radishes in field trials. Chinese Daikon had also sustained significantly higher feeding in laboratory choice tests.

In the evaluation of color traps, the colors Saturn green, Saturn yellow and white caught significantly the highest numbers of flea beetles. These colors are suggested for use in mass trapping or monitoring of flea beetle populations in brassica crop fields.

In evaluation of chemical stimulus baited traps, the mustard oil allyl isothiocynate is shown to be significantly attractive to western cabbage flea beetle adults. Traps baited with allyl isothiocyanate consistently captured significantly more beetles than control traps. Western cabbage flea beetle responded differently to traps baited with allyl isothiocyanate or canola oil. Traps baited with allyl isothiocyanate caught significantly more beetles than traps using canola oil or water (control).

In an effort to identify the concentration level of allyl isothiocyanate that works best to attract flea beetles, paper cup traps baited with 2% allyl isothiocyanate caught significantly more flea beetles than the control. However, yellow colored sticky traps baited with different concentrations of allyl isothiocyanate showed no significant differences in number of flea beetles captured with the different concentrations indicating color stimuli is more attractive than the allyl isothiocyanate.

In evaluations of insecticides and repellents, endosulfan (Thiodan) and esfenvalerate (Asana) were considerably more effective at controlling *P. pusilla* population than imidacloprid (Provado), carbaryl (Sevin), fipronil (Fipronil and Agenda), lambda-cyhalothrin (Warrior), cypermethrin (Mustang and Ammo), permethrin (Ambush), and methomyl (Lannate). In the 1996 trials, Asana treated plots showed 0 flea beetles per plant at one day after the first application and at three days after the second application. Thiodan showed promise as an effective control and a decrease in flea beetles was observed on Thiodan-treated plants at all times. Two weeks after the first application and three weeks after the second application, no treatments maintained control.

Results of repellent evaluations indicate potential in Margosan-O, SunSpray, Azatin and diatomaceous earth in controlling *P. pusilla*. Flea beetles observed on plants treated with Margosan-O reached 0 beetles per plant after the first application and maintained control for up to eight days post treatment in 1996 trial. SunSpray showed slightly similar effect in the 1996 trial but not in 1997 trial. Diatomaceous earth dust was significantly effective in reducing flea beetle densities.

In the 1997 action threshold study, cabbage yields were significantly higher on plots maintained at 0, 2, and 5-flea beetles per plant compared to the control and plots maintained at 10-beetles per plant. As the number of flea beetles reached 10-beetles per plant, the cabbage head weight is reduced compared to 0, 2 or 5-beetles per plant.

In the 1998 action threshold study, all cultivars tested showed significantly larger head diameters and higher yields in all plots treated with the insecticides in all action threshold levels compared to the untreated plots. The head sizes and yields of cabbage cultivar 'Red Acre' maintained at 0-beetles per plant were significantly greater compared to the control and the 10-beetles per plant plots. The head sizes of cabbage cultivar 'Copenhagen Market' measured in plots maintained at 0, 2, 5, and 10-beetles per plant thresholds and yield measured in plots maintained at 0-beetles per plant threshold were greater than the 2 and 10-beetles per plant threshold plots and the control.

Head sizes and yields of broccoli cultivar 'Green Goliath' were significantly greater in the 0, 2, and 5-beetles per plant plots than in the 10-beetles per plant plots and the control. The head sizes and yields of broccoli cultivar 'Premium Crop' were significantly greater in plots maintained at 0-beetles per plant threshold compared to the control and the 2, 5, and 10-beetles per plant threshold plots.

In general, the action threshold that should be utilized to prevent flea beetle damage to crop should be below the 10-beetles per plant density. Since the differences in head sizes and weight were mostly marginal in the lower levels (the thresholds of 0- through 5-beetles per plant), the 5-beetle per plant appears to be the appropriate action threshold for flea beetles control on seedling brassica crops. Seasonal intensity of flea beetles infestation and host plant differences in susceptibility to flea beetles injury may modify this threshold.